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# **A MODULAR RADIATIVE TRANSFER PROGRAM FOR GAS FILTER CORRELATION RADIOMETRY**

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| 16. Abstract<br><br>The fundamentals of a computer program, Simulated Monochromatic Atmospheric Radiative Transfer (SMART), which calculates atmospheric path transmission, solar radiation, and thermal radiation in the 4.6 $\mu\text{m}$ spectral region are described. A brief outline of atmospheric absorption properties and line-by-line transmission calculations is explained in conjunction with an outline of the SMART computational procedures. Program flexibility is demonstrated by simulating the response of a Gas Filter Correlation Radiometer (GFCR) as one example of an atmospheric infrared sensor. Program limitations, input data requirements, program listing, and comparison of SMART transmission calculations are presented. |  |                                                      |  |                                                                                           |  |
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# A MODULAR RADIATIVE TRANSFER PROGRAM FOR GAS FILTER CORRELATION RADIOMETRY

By

Joseph C. Casas<sup>1</sup> and Shirley A. Campbell<sup>2</sup>

## SUMMARY

A line-by-line radiative transfer program that simulates the response of a Gas Filter Correlation Radiometer (GFCR) as a function of altitude is presented and discussed. The program was developed to specifically solve downward viewing GFCR simulation problems, but can be easily adapted to many different infrared sensor requirements. The overlaid structure and specific task subroutines permit desired modifications to be made with ease.

The program performs the task of calculating atmospheric transmittance and upwelling radiance as a function of wave-number, altitude, and primary gas concentration, and writes the results on a temporary storage disk. The program then uses these results to calculate the output response of the GFCR.

Both input and output of the program are described, as well as a sample test case. The FORTRAN variables, subroutines, and overlaid programs are listed and explained. A flowchart is also furnished.

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## INTRODUCTION

The use in recent years of high sensitivity and high effective spectral resolution (less than  $0.1 \text{ cm}^{-1}$ ) instrumentation in the remote measurement of trace atmospheric gases has required refinements in the computational methods utilized in evaluating the atmospheric transmittance in the infrared spectral region. The principle of detection of trace atmospheric gases, specifically gaseous pollutants, has been described by Ludwig (ref. 1). The success of this principle not only depends upon the ability of the instrument technique to discriminate between the pollutant and interfering spectral lines, but also requires an accurate knowledge of high resolution pollutant and atmospheric spectra. This can only be accomplished by applying a line-by-line atmospheric radiative transfer program.

The high resolution of the GFCR instrument requires the usage of a line-by-line program for the purpose of analyzing long path trace atmospheric gas measurements. The program presented in this paper is a combination of an improved version of the line-by-line program described in reference 2 and several desirable characteristics from other line-by-line radiative transfer programs (refs. 3 and 4). The objective was to develop an efficient, generalized line-by-line atmospheric radiative transfer program, which could be readily adapted to many different infrared sensor research needs. The program currently accomodates nadir viewing sensors but can be modified for limb scan sensors via the appropriate geometrical interpretation of atmospheric layer transmission values. This paper describes the program and the basic analytical concepts upon which it is based, as well as its operation.

# SYMBOLS

|               |                                                                                                                      |
|---------------|----------------------------------------------------------------------------------------------------------------------|
| $c_i$         | concentration of absorbing gas, parts per million (ppm)                                                              |
| $C_8$         | Boltzmann distribution constant, cm Kelvin                                                                           |
| $E$           | monochromatic upwelling radiance, watts $\text{cm}^{-2}\text{sr}^{-1}$                                               |
| $E'$          | energy of the lower state, $\text{cm}^{-1}$                                                                          |
| $f$           | Chapman function, dimensionless                                                                                      |
| $h$           | sensor altitude index, dimensionless                                                                                 |
| $h'$          | uppermost layer altitude index, dimensionless                                                                        |
| $H_s$         | wavenumber dependent sun irradiance at the top of the atmosphere, watts $\text{cm}^{-1}\text{sr}^{-2}\text{cm}^{-1}$ |
| $k$           | atmospheric layer index, dimensionless                                                                               |
| $l$           | thickness of layer, cm                                                                                               |
| $m$           | constant, 1.5 for water vapor and 1.0 for all other molecules, dimensionless                                         |
| $N^0$         | Planck blackbody radiation, watts $\text{cm}^{-2}\text{sr}^{-1}$                                                     |
| $p$           | mean pressure of layer, atm (1 atm = $1.01325 \text{ E}+5$ Newtons/meter <sup>2</sup> )                              |
| $p_e$         | equivalent pressure, atm                                                                                             |
| $S_{in}$      | adjusted spectral line intensity, $\text{atm}^{-1}\text{cm}^{-2}$                                                    |
| $S_0$         | spectral line intensity, $\text{atm}^{-1}\text{cm}^{-2}$                                                             |
| $T$           | layer temperature, Kelvin                                                                                            |
| $T_0$         | reference temperature corresponding to spectral line parameters, Kelvin                                              |
| $T_s$         | surface temperature, Kelvin                                                                                          |
| $z$           | altitude index, dimensionless                                                                                        |
| $\alpha_{in}$ | adjusted spectral line half-width, $\text{cm}^{-1}$                                                                  |
| $\alpha_0$    | line half-width, $\text{cm}^{-1}$                                                                                    |

|                |                                                                                 |
|----------------|---------------------------------------------------------------------------------|
| $\beta_{in}$   | Lorentz line shape, dimensionless                                               |
| $\epsilon$     | wavenumber dependent surface emittance, dimensionless                           |
| $\kappa_{in}$  | wavenumber dependent absorption coefficient,<br>$\text{atm}^{-1}\text{cm}^{-1}$ |
| $\tau$         | gaseous transmittance at a particular altitude,<br>dimensionless                |
| $\theta$       | sun zenith angle, degrees                                                       |
| $\omega$       | wavenumber (inverse wavelength), $\text{cm}^{-1}$                               |
| $\bar{\omega}$ | averaged wavenumber, $\text{cm}^{-1}$                                           |

#### SUBSCRIPTS:

|   |                      |
|---|----------------------|
| i | gas species number   |
| n | spectral line number |

#### DICTIONARY OF FORTRAN VARIABLES

|                 |                                                                                                                                         |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| ABSCOF1         | Absorption coefficient for primary gas at<br>OMEGA ( $(\text{cm}^{-1}\text{atm}^{-1})/\text{cm}^{-1}$ ).                                |
| ABSCOF2         | Absorption coefficient for interfering gases<br>at OMEGA ( $(\text{cm}^{-1}\text{atm}^{-1})/\text{cm}^{-1}$ ).                          |
| ABSCOFT         | Total absorption coefficient for all active<br>infrared gases (ABSCOF1 + ABSCOF2) ( $(\text{cm}^{-1}\text{atm}^{-1})/\text{cm}^{-1}$ ). |
| ADJALPH         | Adjusted half-width of WZ ( $\text{cm}^{-1}$ ).                                                                                         |
| ALPHA           | Half-width value at half maximum of WX from<br>spectral line parameter tape ( $\text{cm}^{-1}$ ).                                       |
| ALPHAD (I,NLAY) | Half-width values at half maximum of WZ for<br>a Doppler spectral line for species I ( $\text{cm}^{-1}$ ).                              |
| ALPHAL (I,NLAY) | Adjusted half-width values at half maximum<br>of WZ for a Lorentz spectral line for<br>species I ( $\text{cm}^{-1}$ ).                  |
| ALPHAV (I,NLAY) | Adjusted half-width values at half maximum<br>of WZ for a Voigt spectral line for species<br>I ( $\text{cm}^{-1}$ ).                    |



|                   |                                                                                                                                                                                             |
|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ATMTAU (NLAY,NXM) | For atmospheric layers, calculated transmission of atmosphere at the top of the layer at OMEGA; for instrumentation and calibration layers, calculated transmission of that layer at OMEGA. |
| BBCNEW (NLAYI)    | Radiation of the cold blackbody calibration source attenuated by the vacuum cell at OMEGA.                                                                                                  |
| BBCNEWC (NLAYI)   | Radiation of the cold blackbody calibration source attenuated by the calibration cell and the gas cell at OMEGA.                                                                            |
| BBCNEWG (NLAYI)   | Radiation of the cold blackbody calibration source attenuated by the gas cell at OMEGA.                                                                                                     |
| BBCNEWV (NLAYI)   | Radiation of the cold blackbody calibration source attenuated by the calibration cell and the vacuum cell at OMEGA.                                                                         |
| BBCOLD (NLAYI)    | Radiation of the cold blackbody calibration source attenuated by the vacuum cell at the previous OMEGA.                                                                                     |
| BBCOLD1 (NLAYI)   | Temperature of the cold blackbody calibration source (Kelvin).                                                                                                                              |
| BBCOLDC (NLAYI)   | Radiation of the cold blackbody calibration source attenuated by the calibration cell and the gas cell at the previous OMEGA.                                                               |
| BBCOLDG (NLAYI)   | Radiation of the cold blackbody calibration source attenuated by the gas cell at the previous OMEGA.                                                                                        |
| BBCOLDV (NLAYI)   | Radiation of the cold blackbody calibration source attenuated by the calibration cell and the vacuum cell at the previous OMEGA.                                                            |
| BBHNEW (NLAYI)    | Radiation of the hot blackbody calibration source attenuated by the vacuum cell at OMEGA.                                                                                                   |
| BBHNEWC (NLAYI)   | Radiation of the hot blackbody calibration source attenuated by the calibration cell and the gas cell at OMEGA.                                                                             |
| BBHNEWG (NLAYI)   | Radiation of the hot blackbody calibration source attenuated by the gas cell at OMEGA.                                                                                                      |
| BBHNEWV (NLAYI)   | Radiation of the hot blackbody calibration source attenuated by the calibration cell and the vacuum cell at OMEGA.                                                                          |

|                  |                                                                                                                                         |
|------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| BBHOLD (NLAYI)   | Radiation of the hot blackbody calibration source attenuated by the vacuum cell at the previous OMEGA.                                  |
| BBHOLDC (NLAYI)  | Radiation of the hot blackbody calibration source attenuated by the calibration cell and the gas cell at the previous OMEGA.            |
| BBHOLDG (NLAYI)  | Radiation of the hot blackbody calibration source attenuated by the gas cell at the previous OMEGA.                                     |
| BBHOLDV (NLAYI)  | Radiation of the hot blackbody calibration source attenuated by the calibration cell and the vacuum cell at the previous OMEGA.         |
| BBHOT (NLAYI)    | Temperature of the hot blackbody calibration source (Kelvin).                                                                           |
| BLCKIN (NLAYI)   | Instrument's internal blackbody temperature (Kelvin).                                                                                   |
| BRDFAC           | Primary gas pressure broadening factor.                                                                                                 |
| BROAD            | Primary gas pressure broadening coefficient.                                                                                            |
| C                | $2 * CMINV$ .                                                                                                                           |
| C7               | First radiation constant ( $1.1908E-12$ watts $cm^{-2} sr^{-1} cm^{-1}$ ).                                                              |
| C8               | Boltzmann's constant ( $1.439$ cm K).                                                                                                   |
| C9               | Doppler coefficient ( $6.7675E-8$ ).                                                                                                    |
| CHAPZEN          | Exponential component of the Chapman transmission function of the atmosphere for the solar zenith angle.                                |
| CMINV            | Distance above and below OMEGA considered as center line absorption in the transmittance calculation at wavenumber OMEGA ( $cm^{-1}$ ). |
| COMPABS (I,NLAY) | Line profile component of absorption coefficient at OMEGA.                                                                              |
| COSS             | Cosine of the solar zenith angle.                                                                                                       |
| DELTAW           | Minimum allowable integrating wavenumber increment ( $cm^{-1}$ ).                                                                       |
| DIST             | Width of the spectral band pass.                                                                                                        |

|                           |                                                                                                                                                  |
|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| DV(JJ,NEMIS,NSURF)        | Differential signal resulting from the transmission of external energy between the gas and vacuum cell ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ). |
| EL                        | Energy of lower state of transition of WZ from spectral line parameter tape ( $\text{cm}^{-1}$ ).                                                |
| EMISBB                    | Emissivity of the instrument internal blackbody.                                                                                                 |
| EMISS (NEMIS)             | Thermal emissivity of the earth's surface within the effective field of view.                                                                    |
| ERFC                      | Error function describing the correction for the Voigt profile approximation.                                                                    |
| ERRDN (NLAYI)             | Error in the signal resulting from an imbalance between the optical paths (%).                                                                   |
| FCD                       | Doppler intensity function.                                                                                                                      |
| FCERR                     | Error function for the Voigt intensity approximation.                                                                                            |
| FCL                       | Lorentz intensity function.                                                                                                                      |
| FCV                       | Voigt intensity function.                                                                                                                        |
| FILTERW (NOC)             | Instrument filter wavenumber at which input transmission values are located ( $\text{cm}^{-1}$ ).                                                |
| GASANEW (JJ,NEMIS,NSURF)  | Total upwelling atmospheric radiation attenuated by the gas cell at OMEGA.                                                                       |
| GASAOOLD (JJ,NEMIS,NSURF) | Total upwelling atmospheric radiation attenuated by the gas cell at the previous OMEGA.                                                          |
| GASBNEW (NLAYI)           | Radiation of the internal blackbody attenuated by the gas cell at the previous OMEGA.                                                            |
| GASBOLD (NLAYI)           | Radiation of the internal blackbody attenuated by the gas cell at the previous OMEGA.                                                            |
| GASCONC (ILINE{L},NLAY)   | Concentration of gas ILINE (L) in layer (ppm).                                                                                                   |
| GASENEW (JJ,NEMIS,NSURF)  | Total upwelling atmospheric radiation attenuated by the gas cell including gas cell thermal emission at OMEGA.                                   |

|                              |                                                                                                                                                                                                                                                                                                                                                       |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| GASEOLD (JJ,NEMIS,<br>NSURF) | Total upwelling atmospheric radiation attenuated by the gas cell including gas cell thermal emission at the previous OMEGA.                                                                                                                                                                                                                           |
| GBALDIF (NLAYI)              | Difference of the radiation from the hot and cold blackbody balance sources attenuated by the gas cell path.                                                                                                                                                                                                                                          |
| GCLTAIN (NLAYI)              | Average transmission of the gas cell for the internal blackbody radiation.                                                                                                                                                                                                                                                                            |
| IDENT (16)                   | Identification numbers corresponding to active infrared gas.<br><br>1 - Carbon Monoxide (CO)<br>2 - Water (H <sub>2</sub> O)<br>3 - Sulfur Dioxide (SO <sub>2</sub> )<br>4 - Ammonia (NH <sub>3</sub> )<br>5 - Methane (CH <sub>4</sub> )<br>7 - Nitrous Oxide (N <sub>2</sub> O)<br>10 - Nitric Oxide (NO)<br>12 - Carbon Dioxide (CO <sub>2</sub> ) |
| ILINE (NOMEG)                | Array of identification numbers corresponding to spectral lines in OMEGSTR.                                                                                                                                                                                                                                                                           |
| IPOINT                       | Working pointer for OMEGSTR.                                                                                                                                                                                                                                                                                                                          |
| IPOLLUT                      | Identification number of primary gas.                                                                                                                                                                                                                                                                                                                 |
| IS                           | Identification number of species WZ from spectral line parameter tape.                                                                                                                                                                                                                                                                                |
| JCOUNT                       | Number of integration steps.                                                                                                                                                                                                                                                                                                                          |
| JPROF (NLAY)                 | Line profile array: 1 if Lorentzian, 2 if Voigt.                                                                                                                                                                                                                                                                                                      |
| KBI                          | Number of atmospheric layers.                                                                                                                                                                                                                                                                                                                         |
| MOLWT(IS)                    | Array of molecular weights corresponding to the IDENT array.                                                                                                                                                                                                                                                                                          |
| MOLWTIS                      | Molecular weight of species IS (grams/molecules).                                                                                                                                                                                                                                                                                                     |
| NEMIS                        | Number of earth's emissivities to be considered.                                                                                                                                                                                                                                                                                                      |
| NLAY                         | Total number of input homogeneous layers (atmospheric + instrument + calibration).                                                                                                                                                                                                                                                                    |

|                   |                                                                                                                                                                                                                                                                                                                      |
|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NLAYI             | Number of instrument layers.                                                                                                                                                                                                                                                                                         |
| NOC               | Number of input FILTERW values.                                                                                                                                                                                                                                                                                      |
| NOMEG             | Number of spectral lines in OMEGSTR.                                                                                                                                                                                                                                                                                 |
| NSPEC             | Number of active infrared gases being considered.                                                                                                                                                                                                                                                                    |
| NSTORW            | Number of spectral lines in WSTOR.                                                                                                                                                                                                                                                                                   |
| NSUN              | Number of input SUNW values.                                                                                                                                                                                                                                                                                         |
| NSURF             | Number of surface temperatures to be considered.                                                                                                                                                                                                                                                                     |
| NXM               | Number of primary gas concentration multipliers (XMULT).                                                                                                                                                                                                                                                             |
| OMEGA             | The center wavenumber of the subinterval being considered for transmittance calculations ( $\text{cm}^{-1}$ ).                                                                                                                                                                                                       |
| OMEGSTR(NOMEG)    | Array of spectral lines from OMEGA-CMINV to OMEGA + CMINV.                                                                                                                                                                                                                                                           |
| OPATH (NLAY)      | Optical path of layer (atm-cm).                                                                                                                                                                                                                                                                                      |
| PLANCK            | Thermal emission of layer at OMEGA ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ).                                                                                                                                                                                                                                         |
| PLANK (NLAYI)     | Thermal emission of the instrument's internal blackbody at OMEGA ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ).                                                                                                                                                                                                           |
| PRES (NLAY)       | Pressure of layer (atm).                                                                                                                                                                                                                                                                                             |
| PROFAC1 (I,NLAY)  | Multiplicative variable for line profile.                                                                                                                                                                                                                                                                            |
| PROFAC2 (I,NLAY)  | Multiplicative variable for line profile ( $ \omega - \omega_0 /\text{ALPHA}$ ).                                                                                                                                                                                                                                     |
| RADATM (NLAY,NXM) | For atmospheric layers, the radiation upwelling from the atmosphere as a result of atmospheric gaseous molecular emission at OMEGA; for instrument and calibration layers, the radiation as a result of gaseous molecular emission of that layer at OMEGA ( $(\text{watts cm}^{-2}\text{sr}^{-1})/\text{cm}^{-1}$ ). |

|                              |                                                                                                                                                                                                                                                                                      |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RADCOLC (NLAYI)              | Integrated radiation of the cold blackbody calibration source attenuated by the calibration cell and the gas cell.                                                                                                                                                                   |
| RADCOLD (NLAYI)              | Integrated radiation of the cold blackbody calibration source attenuated by the vacuum cell.                                                                                                                                                                                         |
| RADCOLG (NLAYI)              | Integrated radiation of the cold blackbody calibration source attenuated by the gas cell.                                                                                                                                                                                            |
| RADCOLV (NLAYI)              | Integrated radiation of the cold blackbody calibration source attenuated by the calibration and vacuum cells.                                                                                                                                                                        |
| RADGASA (JJ,NEMIS,<br>NSURF) | Integrated total upwelling atmospheric radiation attenuated by the gas cell.                                                                                                                                                                                                         |
| RADGASB (NLAYI)              | Integrated radiation of the internal blackbody attenuated by the gas cell.                                                                                                                                                                                                           |
| RADGASE (JJ,NEMIS,<br>NSURF) | Integrated total upwelling atmospheric radiation attenuated by the gas cell including gas cell thermal emission.                                                                                                                                                                     |
| RADHOT (NLAYI)               | Integrated radiation of the hot blackbody calibration source attenuated by the vacuum cell.                                                                                                                                                                                          |
| RADHOTC (NLAYI)              | Integrated radiation of the hot blackbody calibration source attenuated by the calibration cell and the gas cell.                                                                                                                                                                    |
| RADHOTG (NLAYI)              | Integrated radiation of the hot blackbody calibration source attenuated by the gas cell.                                                                                                                                                                                             |
| RADHOTV (NLAYI)              | Integrated radiation of the hot blackbody calibration source attenuated by the calibration cell and the vacuum cell.                                                                                                                                                                 |
| RADOLD (NLAY,NXM)            | For atmospheric layers, the radiation upwelling from the atmosphere as a result of atmospheric gaseous molecular emission at the previous OMEGA; for instrument and calibration layers, the radiation as a result of gaseous molecular emission of that layer at the previous OMEGA. |
| RADOTOT (JJ,NEMIS,<br>NSURF) | Total upwelling radiation at the previous OMEGA.                                                                                                                                                                                                                                     |

|                              |                                                                                                                                                              |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RADSOLD (JJ,NEMIS,<br>NSURF) | Radiation upwelling from the atmosphere<br>as a result of earth surface emission at<br>the previous OMEGA.                                                   |
| RADSUN (NLAY,NEMIS,<br>NXM)  | Radiation upwelling from the atmosphere as<br>a result of incident solar energy at<br>OMEGA ((watts cm <sup>-2</sup> sr <sup>-1</sup> )/cm <sup>-1</sup> ).  |
| RADSUNO (NLAY,NEMIS,<br>NXM) | Radiation upwelling from the atmosphere<br>as a result of incident solar energy at<br>the previous OMEGA.                                                    |
| RADSURF (JJ,NEMIS,<br>NSURF) | Radiation upwelling from the atmosphere<br>as a result of earth surface emission at<br>OMEGA ((watts cm <sup>-2</sup> sr <sup>-1</sup> )/cm <sup>-1</sup> ). |
| RADTOT (JJ,NEMIS<br>NSURF)   | Total upwelling radiation at OMEGA<br>(RADSUN + RADSURF + RADATM) ((watts<br>cm <sup>-2</sup> sr <sup>-1</sup> )/cm <sup>-1</sup> ).                         |
| RADVACA (JJ,NEMIS,<br>NSURF) | Integrated total upwelling atmospheric<br>radiation attenuated by the vacuum cell.                                                                           |
| RADVACB (NLAYI)              | Integrated radiation of the internal<br>blackbody attenuated by the vacuum cell.                                                                             |
| RATLV (I,NLAY)               | Ratio of Lorentz to Voigt half-widths<br>for species I.                                                                                                      |
| REFTEMP (I)                  | Reference temperature corresponding to<br>identification numbers of spectral line<br>parameters from tape (Kelvin).                                          |
| RESPG (NOC)                  | Normalized transmission values for gas<br>cell given at FILTERW.                                                                                             |
| RESPIN                       | Instrument detector response.                                                                                                                                |
| RESPV (NOC)                  | Normalized transmission values for<br>vacuum cell given at FILTERW.                                                                                          |
| ROOTEMP (NLAY)               | Square root of layer temperature.                                                                                                                            |
| S                            | Adjusted line strength of WZ (atm <sup>-1</sup> cm <sup>-2</sup> ).                                                                                          |
| SIGAV (JJ,NEMIS,<br>NSURF)   | Signal resulting from external blackbody<br>radiation attenuated by the vacuum cell<br>and the aperture (watts cm <sup>-2</sup> sr <sup>-1</sup> ).          |
| SIGBV (NLAYI)                | Signal resulting from the internal<br>blackbody radiation attenuated by the<br>vacuum cell and the aperture (watts<br>cm <sup>-2</sup> sr <sup>-1</sup> ).   |

|                        |                                                                                                                                                                                                                   |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SUNCOM (NEMIS)         | Component of solar energy unattenuated by the atmosphere ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ).                                                                                                                |
| SUNFLUX (NSUN)         | Wavenumber dependent solar energy incident at the top of the atmosphere ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ).                                                                                                 |
| SUNINTP                | Interpolated solar energy at OMEGA.                                                                                                                                                                               |
| SUNW (NSUN)            | Wavenumbers corresponding to the SUNFLUX input values.                                                                                                                                                            |
| SURFCOM (NEMIS, NSURF) | Component of surface energy contribution unattenuated by the atmosphere ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ).                                                                                                 |
| SZ                     | Line strength values of WZ from spectral line parameter tape ( $\text{atm}^{-1}\text{cm}^{-2}$ ).                                                                                                                 |
| TAU (NXM)              | Transmission of layer at OMEGA.                                                                                                                                                                                   |
| TAUA (NLAYI)           | Calculated average transmission coefficient for the vacuum cell aperture required to balance the optical paths for two external blackbody temperatures.                                                           |
| TAUGFIL                | Interpolated transmittance of gas cell filter at OMEGA.                                                                                                                                                           |
| TAUOLD (NLAY, NXM)     | For atmospheric layers, the calculated transmission of the atmosphere at the top of the layer at the previous OMEGA; for instrument and calibration layers, the transmission of that layer at the previous OMEGA. |
| TAUSLAT (NXM)          | Total atmospheric slant path coefficient.                                                                                                                                                                         |
| TAUVFIL                | Interpolated transmittance of vacuum cell filter at OMEGA.                                                                                                                                                        |
| TCONSQ                 | Temperature dependence of the rotational partition function; $(\text{TEMPCON})^2$ unless water, which is $(\text{TEMPCON})^{5/2}$ .                                                                               |
| TEMP (NLAY)            | Temperature of layer (Kelvin).                                                                                                                                                                                    |
| TEMPCON                | Reference temperature of gas/temperature of layer (temperature adjustment for line half-width).                                                                                                                   |
| TERFC                  | Error function term for Voigt profile.                                                                                                                                                                            |



|                           |                                                                                                                                                                                                                                                               |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| TERFC2                    | TERFC squared.                                                                                                                                                                                                                                                |
| THICK (NLAY)              | Thickness of layer (cm).                                                                                                                                                                                                                                      |
| TINV (NLAY)               | Inverse of layer temperature.                                                                                                                                                                                                                                 |
| TOTATM (NLAY,NXM)         | For atmospheric layers, the integrated radiation upwelling from the atmosphere as a result of atmosphere gaseous molecular emission; for instrument and calibration layers, the integrated radiation as a result of gaseous molecular emission of that layer. |
| TOTRAD (JJ,NEMIS, NSURF)  | Total integrated upwelling radiation.                                                                                                                                                                                                                         |
| TOTSUN (NLAY,NEMIS, NXM)  | Integrated radiation upwelling from the atmosphere as a result of incident solar energy.                                                                                                                                                                      |
| TOTSURF (JJ,NEMIS, NSURF) | Integrated radiation upwelling from the atmosphere as a result of earth surface emission.                                                                                                                                                                     |
| TRANS (NLAY,NXM)          | For atmospheric layers, the calculated integrated transmission of the atmosphere at the top of the layer; for instrument and calibration layers, the integrated transmission of that layer.                                                                   |
| TSURF (NSURF)             | Temperature of the earth's surface within the effective field of view (Kelvin).                                                                                                                                                                               |
| V (JJ,NEMIS,NSURF)        | Average signal resulting from the transmission of external energy between the gas and vacuum cells ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ).                                                                                                                  |
| VACANEW (JJ,NEMIS, NSURF) | Total upwelling atmospheric radiation attenuated by the vacuum cell at OMEGA.                                                                                                                                                                                 |
| VACAOLD (JJ,NEMIS, NSURF) | Total upwelling atmospheric radiation attenuated by the vacuum cell at the previous OMEGA.                                                                                                                                                                    |
| VACBNEW (NLAYI)           | Radiation of the internal blackbody attenuated by the vacuum cell at OMEGA ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ).                                                                                                                                          |
| VACBOLD (NLAYI)           | Radiation of the internal blackbody attenuated by the vacuum cell at the previous OMEGA ( $\text{watts cm}^{-2}\text{sr}^{-1}$ ).                                                                                                                             |

|                 |                                                                                                                                                       |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| VBALDIF (NLAYI) | Difference of the radiation from the hot and cold blackbody balance sources attenuated by the vacuum cell path.                                       |
| VGTPAR          | A Voigt parameter.                                                                                                                                    |
| VGTPAR2         | Reciprocal of the Voigt parameter squared.                                                                                                            |
| VGTPAR4         | VGTPAR squared.                                                                                                                                       |
| W3              | OMEGA cubed.                                                                                                                                          |
| WI              | Initial wavenumber used for transmittance calculation ( $\text{cm}^{-1}$ ).                                                                           |
| WF              | Final wavenumber used for transmittance calculation ( $\text{cm}^{-1}$ ).                                                                             |
| WRATLV          | Ratio of Lorentz to Voigt half-widths for WZ.                                                                                                         |
| WRATV1          | $1 - \text{WRATLV}$ .                                                                                                                                 |
| WSTOR (NSTORW)  | Array of spectral lines, the first of which is $\leq \text{OMEGA}$ and the remainder are $\geq \text{OMEGA}$ but $\leq \text{OMEGA} + \text{CMINV}$ . |
| WZ              | Wavenumber values from spectral line parameter tape ( $\text{cm}^{-1}$ ).                                                                             |
| XMULT (NXM)     | Primary gas concentration multipliers.                                                                                                                |
| ZENITH          | Sun zenith angle (degrees).                                                                                                                           |

#### PROBLEM DEFINITION AND METHOD OF SOLUTION

A line-by-line radiative transfer computer program was needed to efficiently perform the task of data reduction for several versions of the GFCR which are being developed by NASA/Langley Research Center (LaRC). The writing of the SMART program was undertaken to minimize data reduction cost by the efficient utilization of computer storage through overlaying, by reducing execution time, and by combining several phases of the previous data reduction procedure, i.e., instrument balance and calibration (ref. 1) and data signal simulation. The modular

structure of the program was designed to permit modifications of the computational algorithms without affecting the program framework. The individual overlaid programs and subroutines are explained in the Program Organization and Description section. In addition, thorough documentation was necessary for program clarity.

In order to minimize computation time without a loss in accuracy, certain assumptions were made concerning the atmosphere and radiative transfer processes in the algorithms used to perform transmittance calculations. To compute the transmittance from the earth's surface to a sensor altitude,  $h$ , the modeled atmosphere between these points is divided into a number of homogeneous layers, i.e., regions within which the temperature, total pressure, and concentrations of the primary and interfering molecular absorbers are uniform. The error in this approximation may be made as small as desired by subdividing the atmosphere into a sufficiently large number of layers. The total radiance incident on a sensor at altitude  $h$  is given by

$$E(h) = \int_{\Delta\omega} E(\omega) d\omega \quad (1)$$

where  $\Delta\omega$  is the spectral bandpass of interest and  $E(\omega)$  is the total monochromatic upwelling radiance.

For a cloud-free, non-scattering atmosphere under local thermodynamic equilibrium, the atmospheric radiative transfer equation for the total monochromatic upwelling radiant energy,  $E(\omega)$ , as viewed by a nadir type of sensor can be written as

$$\begin{aligned}
E(\omega) = & \varepsilon(\omega) N^O(\omega, T_s) \tau(\omega, h) \\
& + \int_0^h N^O(\omega, T(z)) \frac{d\tau(\omega, z)}{dz} dz \\
& + \frac{1}{\pi} [1 - \varepsilon(\omega)] \cos \theta H_s(\omega) \\
& \cdot [\tau(\omega, h)] [\tau(\omega, h')] f(\theta)
\end{aligned} \tag{2}$$

where  $\varepsilon(\omega)$  is the wavenumber dependent surface emittance,  $N^O(\omega, T_s)$  is the Planck blackbody function which is dependent on wavenumber and surface temperature,  $T_s$ , or radiating gas temperature at a particular altitude,  $T(z)$ . The monochromatic transmittance of the atmosphere between the emitting surface  $z$  and the altitude of the sensor,  $h$ , is represented by  $\tau(\omega, h)$ , and the monochromatic vertical transmission of the entire modeled atmosphere is represented by  $\tau(\omega, h')$ . The solar zenith angle is  $\theta$  and the wavenumber dependent sun irradiance at the top of the atmosphere is  $H_s$ . The Chapman function (ref. 1),  $f(\theta)$ , is equal to  $\sec \theta$  for  $0^\circ \leq \theta \leq 60^\circ$  and is equal to the Chapman polynomial for  $\theta > 60^\circ$ . The three terms on the right-hand side of equation (2) represent, respectively, the earth's surface emission, the atmospheric emission, and the solar reflected energy (see figure 1). All of these components must be considered in the solar-thermal overlap region at  $4.6 \mu\text{m}$ . These terms are represented in SMART by RADSURF, RADATM, and RADSUN, respectively.

A closer examination of the form of equations (1) and (2) indicates two very distinct differences between the methodology of SMART and other conventional line-by-line radiative transfer programs. The first difference is the order in which the integrals over  $\Delta\omega$  and over the change in altitude,  $\Delta h$ , are performed. By initially integrating over  $\Delta h$  monochromatically, the inflexibility of transmittance averaging is eliminated, i.e.,

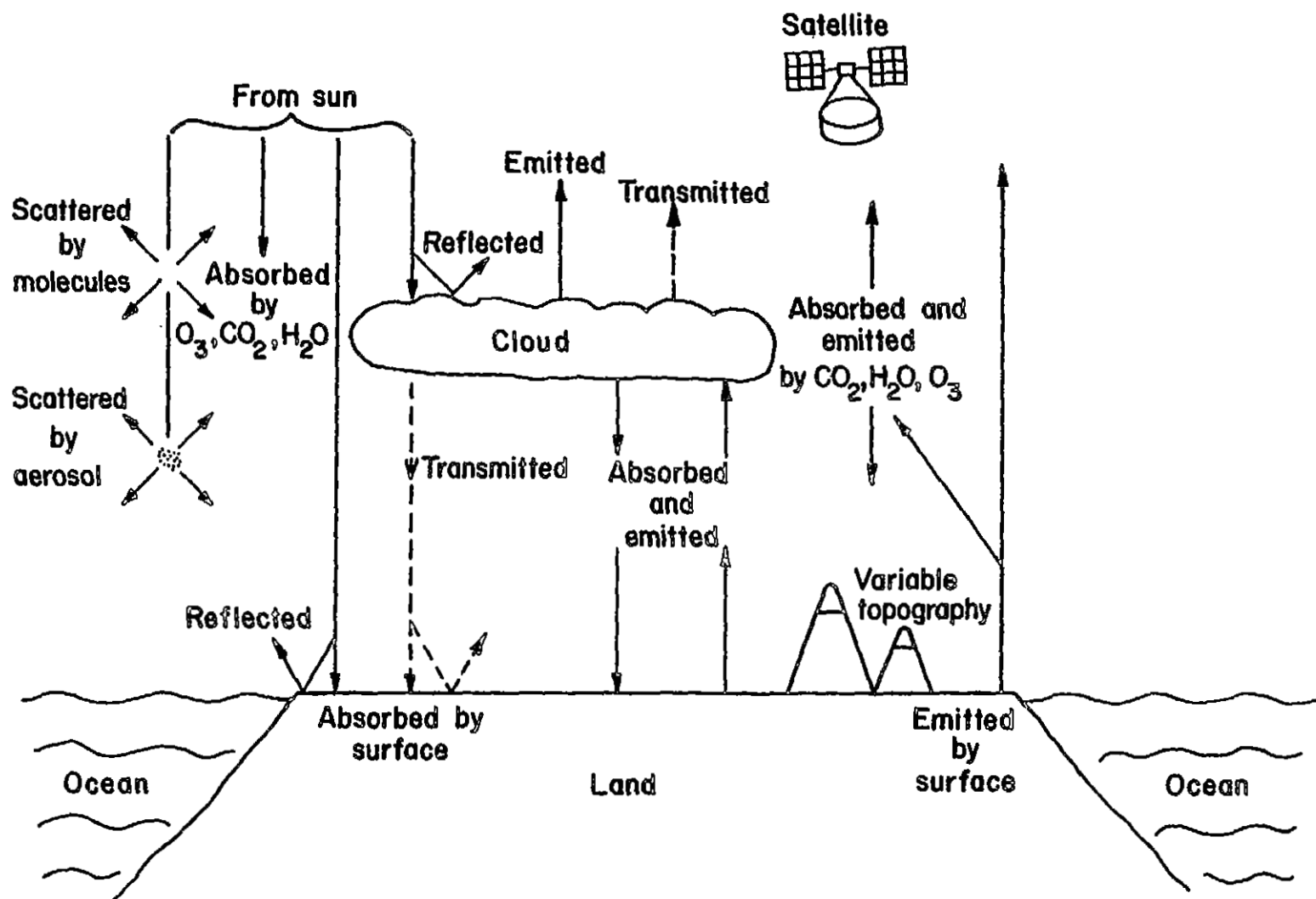


Figure 1. Interaction of radiation with the atmosphere.

the monochromatic transmission at any altitude  $h$  is given by

$$\tau(\omega, h) = \prod_{z=1}^h \tau(\omega, z) \quad (3)$$

and not by

$$\bar{\tau}(\Delta\omega, h) = \frac{1}{\Delta\omega} \sum_{\Delta\omega} \left[ \prod_{z=1}^h \tau(\omega, z) \right]. \quad (4)$$

The spectral resolution of the transmittance values, i.e., the number of  $\omega$ 's at which the absorption coefficient is calculated, is defined by the user in subroutine GETW. The algorithm used for our CO calculations is explained later in this section.

The second difference between SMART and most other line-by-line radiative transfer programs is the specification of the order of limits of integration over altitude. The lower limit of integration is the radiating source and the upper limit is the sensor altitude which allows for practical computation of the monochromatic and total integrated transmission at the top of each atmospheric layer as seen by equation (3). This eliminates redundant calculations of atmospheric transmittance in evaluating signals from aircraft platform sensors at various altitudes.

Theoretically, the total absorption coefficient at any wavenumber,  $\omega$ , consists of contributions from all spectral lines; however, for practical computational purposes, only lines within the vicinity of  $\omega$  are considered for calculation in SMART. The contribution to the absorption coefficient of lines in the vicinity of  $\omega$  can be divided into two parts, direct and wing. Those lines which lie within an interval defined by approximately 100 half-widths of the primary gas to each side of  $\omega$  are considered to be the direct contributors

to the absorption coefficient, while those lines lying outside of this interval result in wing absorption. In the SMART calculation of direct line absorption contribution, at each incremented step a symmetric interval (CMINV) is considered about the center wavenumber. This interval is constant throughout the entire band. For atmospheric carbon monoxide using the Lorentzian line profile, an interval of  $5 \text{ cm}^{-1}$  was selected since this value was approximately 100 times the line half-width of CO. For spectral lines beyond  $5 \text{ cm}^{-1}$ , the direct contribution to the absorption coefficient is very small (ref. 8). Presently, the SMART program does not include wing contribution.

The SMART program is divided into two primary level overlays (see figure 2). The first lower level overlay, as described in the Program Organization and Description section, performs initialization of all variables required for the calculation of the monochromatic gas transmission (TAU) for each atmospheric, instrument cell, and instrument calibration layer. The procedure for the computation of TAU is initiated by a call of the READTP subroutine, which reads all spectral reference information; i.e., line position (WZ), half-width (ALPHA), intensity (SZ), lower energy level (EL), and species identification number (IS) from the spectral line parameter reference tape for the band interval  $WI - CMINV$  to  $WF + CMINV$ . To analyze the GFCR sensor carbon monoxide data measurements in the  $4.6 \text{ } \mu\text{m}$  region, the McClatchey spectral line parameter tape (ref. 5) was used to obtain all spectral reference information. The parameters read should be under room temperature and standard pressure (296.0 K and 1 atm) conditions or the appropriate conversion must be performed prior to reading these parameters in subroutine READTP (see Appendix C).

The gaseous transmittance at a particular altitude as a function of wavenumber is given by

$$TAU(\omega) = \tau(\omega) = \exp \left[ - \sum_i \kappa_i(\omega) p c_i l \right] \quad (5)$$

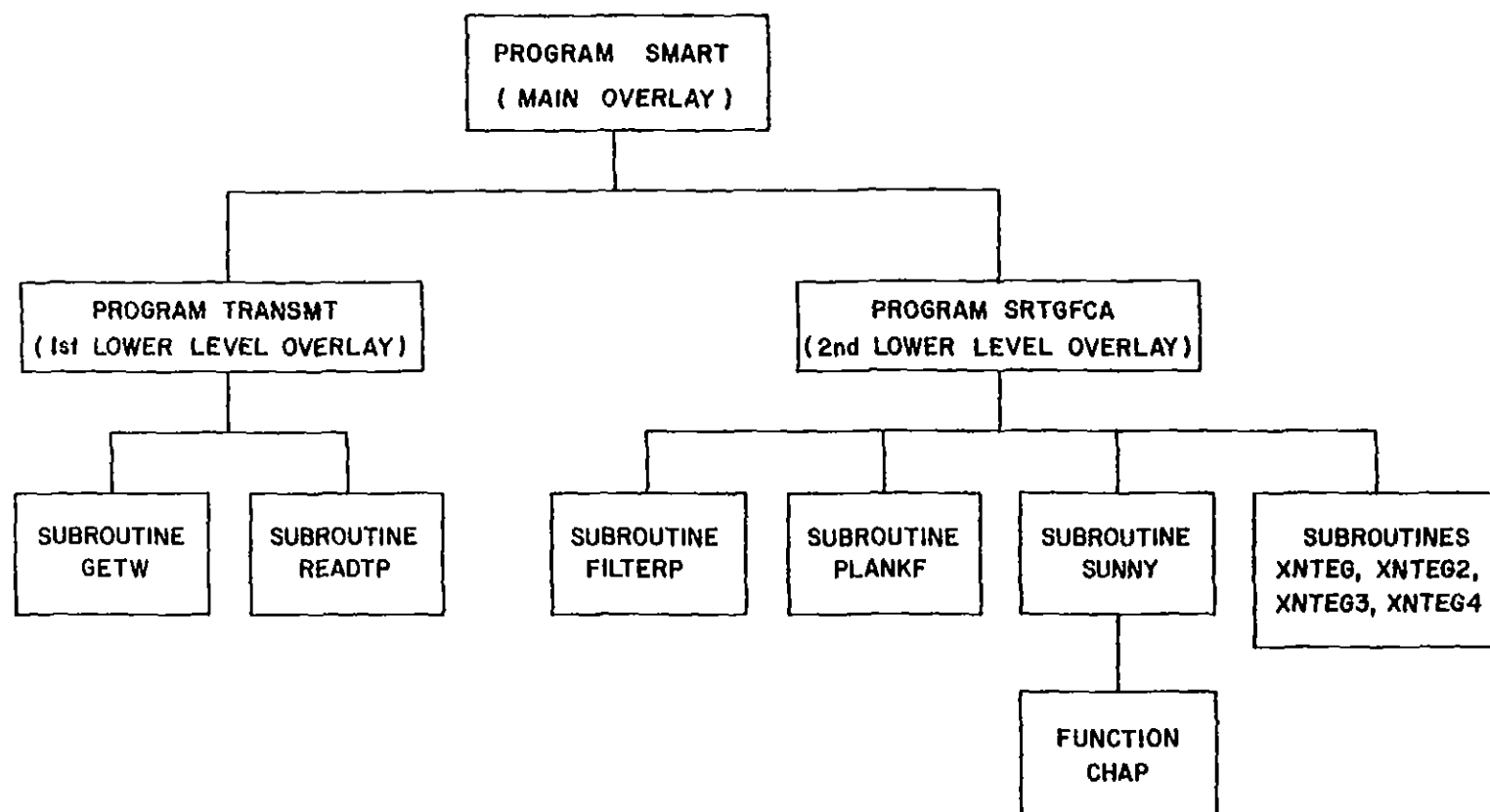


Figure 2. SMART program structure.



where  $\kappa_i(\omega)$  is the wavenumber dependent absorption coefficient of gas species  $i$  (their sum being ABSOFT),  $p$  (PRES) is the total mean pressure of layer  $k$ ,  $c_i$  (GASCONC) is the concentration of absorbing gas  $i$ , and  $\ell$  (THICK) is the thickness of the  $k$ th layer.

In general, the absorption coefficient of the  $n$ th line of species  $i$  is described by

$$\kappa_{in}(\omega) = S_{in} \beta_{in}(\omega) \quad (6)$$

where  $S_{in}$  is the layer temperature (TEMP) corrected line intensity and  $\beta_{in}$  is the line shape function, i.e., Lorentz, Voigt, or Doppler. The Lorentz line shape is given by

$$\beta_{in}(\omega) = \frac{1}{\pi} \frac{\alpha_{in}}{(\omega - \omega_{in})^2 + (\alpha_{in})^2} \quad (7)$$

where  $\alpha_{in}$  (ADJALPH) is the temperature and pressure dependent line half-width for layer  $k$  and is calculated by

$$\text{ADJALPH} = \alpha_{in} = \alpha_o p_e \left( \frac{T_o}{T} \right)^{1/2} . \quad (8)$$

The reference line half-width,  $\alpha_o$  (ALPHA), is read from the spectral line parameter tape at temperature  $T_o$  (REFTEMP). The equivalent pressure,  $p_e$ , is a function of the ratio of self-broadening to the nitrogen-broadening efficiency (BROAD), the total pressure (PRES), and the concentration of the absorbing gas (GASCONC) as given by

$$p_e = [\text{GASCONC} * (\text{BROAD} - 1) + 1] * \text{PRES} . \quad (9)$$

In the case of trace gases in the atmosphere, the equivalent pressure is set equal to the total atmospheric pressure since

self-broadening is insignificant. For instrument and calibration layers, self-broadening is assumed and the corresponding equivalent pressure for BROAD is calculated.

The line intensity (S) depends upon the temperature through the Boltzman distribution factor (ref. 6) and is expressed as

$$S_{in} = S_o \left( \frac{T_o}{T} \right)^m \exp \left[ -C8 \left( \frac{T_o}{T} - 1 \right) \frac{E'}{T_o} \right] \quad (10)$$

or

$$S = SZ * TCONSQ * EXP [-C8*(TEMPCON - 1)*EL/REFTEMP] \quad (11)$$

where  $m$  is 1.5 for water vapor and ozone and 1.0 for other infrared active molecules, such as CO, CO<sub>2</sub>, N<sub>2</sub>O, and C8 is the Boltzman distribution constant. At this point, the user has the option of calculating ABSOFT as determined by the Lorentz function or as determined by an approximation to the Voigt function detailed by Kielkopf (ref. 7). The flexibility of SMART allows easy insertion of the Doppler line profile calculation by the addition of an option as defined by JPROF in the same program location as the Lorentz and Voigt function. The line shape for each layer (JPROF) must be designated in the input and need not be the same for each layer. The direct contribution to the absorption coefficient from all infrared active lines whose center positions lies within CMINV of the wavenumber under consideration (OMEGA), i.e., the interval OMEGA - CMINV to OMEGA + CMINV, constitutes the total direct absorption at OMEGA. For additional spectral line information, the interval of direct contribution can easily be extended by increasing the dimensions of the appropriate variables. The total absorption at OMEGA for this interval is determined by the summation of the absorption coefficients for all lines within the interval. In addition, the user can automatically

obtain the total absorption coefficient (ABCOFT) that corresponds to a maximum of ten different primary gas vertical mixing ratio profiles as defined by XMULT. Each value of XMULT is multiplied by the volume mixing ratio of the primary gas in every layer resulting in a bias shifting of the input vertical mixing ratio profile. ABSCOFT is calculated as the sum of two components, ABSCOF1, which is the absorption coefficient for the primary gas, and ABSCOF2, which is the absorption coefficient for all other interfering gases. The absorption effects of continua, such as nitrogen and water vapor, could easily be considered in the form of an added third term to ABSCOFT after the necessary algorithms for accurately calculating the continuum absorption in the spectral region under consideration have been developed.

After completion of the monochromatic calculation of ABSCOFT at OMEGA for the first layer, the transmittance is calculated as shown by equation (5). This procedure is repeated resulting in a TAU value for each layer  $k$ . The self-emission (RADATM) of each layer is then calculated via the wavenumber dependent energy described by the Planck blackbody function used in subroutine PLANKF. The temperature used in PLANKF is the mean temperature (TEMP) of the emitting layer. The emissivity (EMISS) of the layer is determined by the calculated transmittance of that layer as given by

$$EMISS = 1 - TAU . \quad (12)$$

The total monochromatic transmittance (ATMTAU) at the top of each atmospheric layer is then calculated as

$$ATMTAU(\omega) = \prod_k TAU_k(\omega) \quad (13)$$

and written on temporary storage disk 6 with the corresponding wavenumber and self-emission component.

The next operation performed by SMART is the determination of the wavenumber increment step size for the purpose of repeating the transmittance calculations for the entire spectral band being considered, i.e.,  $WI - CMINV$  to  $WF + CMINV$ . This task is accomplished by the GETW subroutine. The size of the wavenumber increment used in absorption coefficient calculations is arbitrary and depends upon the spectral resolution required by the user, since the absorption coefficient varies rapidly as a function of relative position to the spectral line centers. Subroutine GETW can be replaced by any of several schemes (refs. 4, 8, and 9) proposed for selection of wavenumber positions for line-by-line absorption calculations. For applications of SMART to the GFCR carbon monoxide sensor, a minimum mesh size (DWMIN) of  $.01 \text{ cm}^{-1}$  and a maximum mesh size of  $.5 \text{ cm}^{-1}$ , which is  $1/8$  of the average distance between CO spectral lines, was determined to most efficiently describe the wavenumber dependent absorption coefficient. When the spectral line density being examined is high, a large number of integration points are calculated; however, if the spectral line density is low, fewer points of integration are considered. The transmittance calculation for a new OMEGA is performed and the corresponding results, i.e.,  $ATMTAU(\omega)$  and  $RADATM(\omega)$ , are written on temporary storage disk 6. This procedure is repeated until  $ATMTAU$  and  $RADATM$  for the entire spectral band are written.

The second lower level overlay is comprised of four sections. The first section of the overlay reads the input data required for computation of instrument parameters, and the remaining variables of the RADSURF and RAD SUN contributions given by equation (2). After initialization of variables, subroutine FILTERP is called to evaluate by interpolation the wavenumber dependent variables, i.e., instrument filter functions and solar irradiance values. The second section calculates the earth's monochromatic emission (RADSURF) as a function of one or more surface temperatures and emissivities. This task is accomplished by employing subroutine PLANKF in

the calculation of the wavenumber dependent Planck distribution of energy.

The solar contribution (RAD SUN) is calculated in accordance with equation (2) by subroutine SUNNY, where the Chapman function is employed in determining the slant path transmittance of incident solar radiance. The three terms of equation (2), i.e., RAD SURF, RAD ATM, and RAD SUN, are then obtained by attenuating each component by the appropriate atmospheric transmittance (ATMTAU) value for an altitude corresponding to the top of each atmospheric layer.

The third section calculates the internal radiance values for the GFCR sensor and the necessary parameters for balance and calibration. [A detailed description of instruments based on the gas filter correlation technique is presented in references 1 and 2]. In addition, the simulated signals (DV and V) corresponding to the sensor detection of total upwelling radiance (RADTOT) are calculated. For convenience, the trapezoidal rule is used for integration of all variables over the spectral band being examined. This process is performed by the subroutines XNTEG, XNTEG2, XNTEG3, and XNTEG4. The dimensions of the variables to be integrated determines which of the four subroutines is called. The required output parameters, both atmospheric and sensor, are then stored and are readily accessible for output listing in section four.

#### PROGRAM ORGANIZATION AND DESCRIPTION

The SMART program is written in FORTRAN IV for the Control Data Cyber series computer systems and is overlaid. For our sample test case using 17 input layers, the storage required is 130300 octal words. The storage is dependent upon the number of atmospheric and instrument layers required for calculations. Each additional layer requires approximately 2000 octal words.

Each overlaid program and its subroutines are listed on the following pages. For each program or subroutine, the required number of octal words of storage and an explanation of the function are presented. A dictionary of FORTRAN variables used was given in a previous section. A flow chart showing the logic flow and the interrelation of the various programs and subroutines is shown in figure 3.

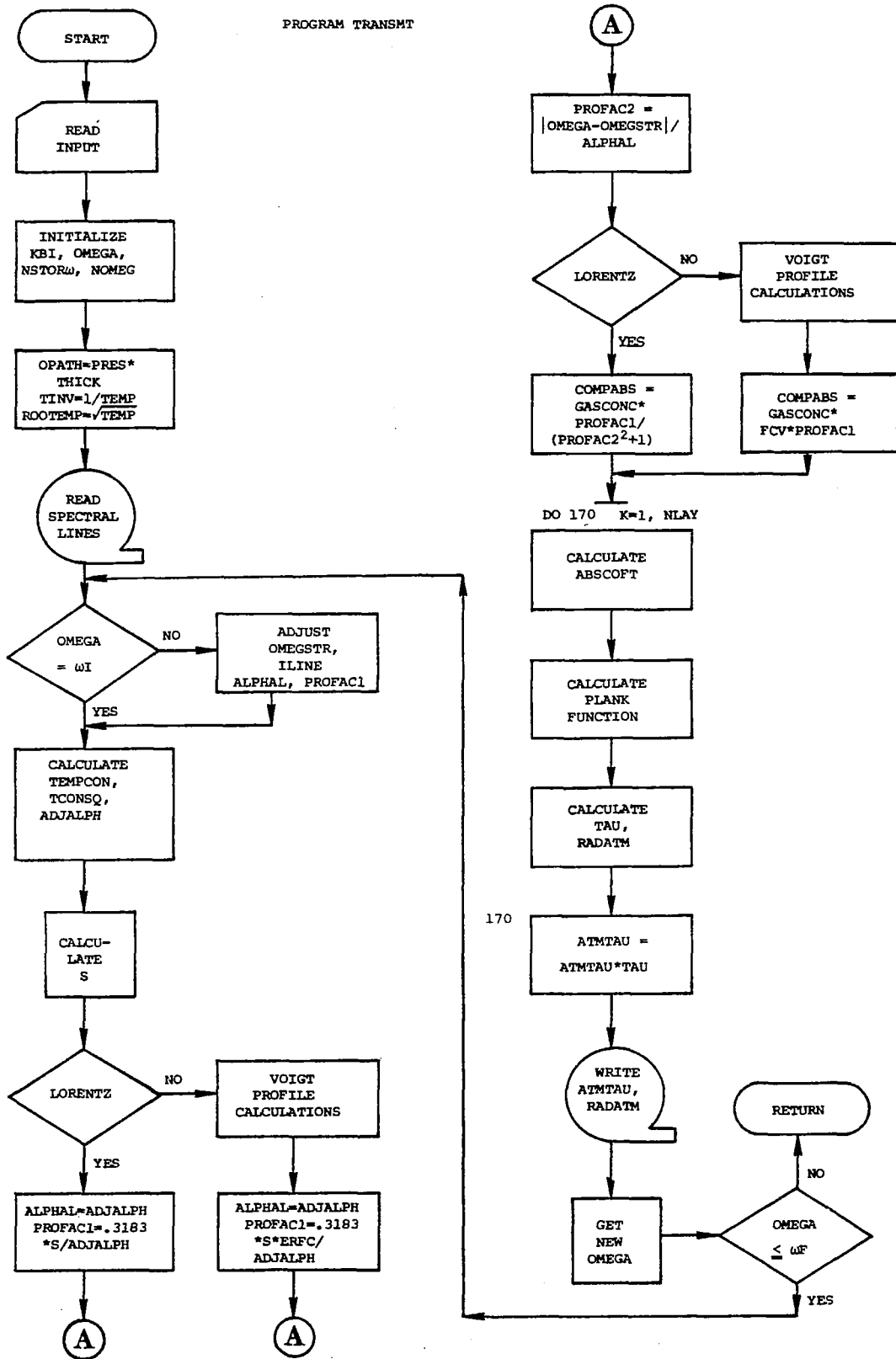
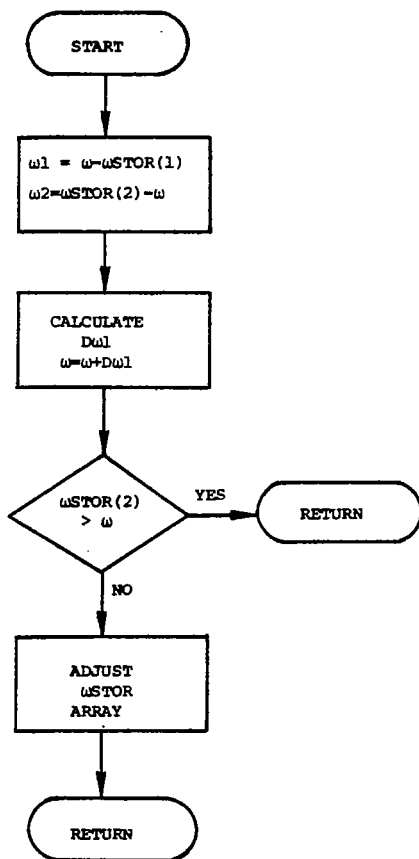


Figure 3. Flowchart of SMART program.

SUBROUTINE GETW



SUBROUTINE READTP

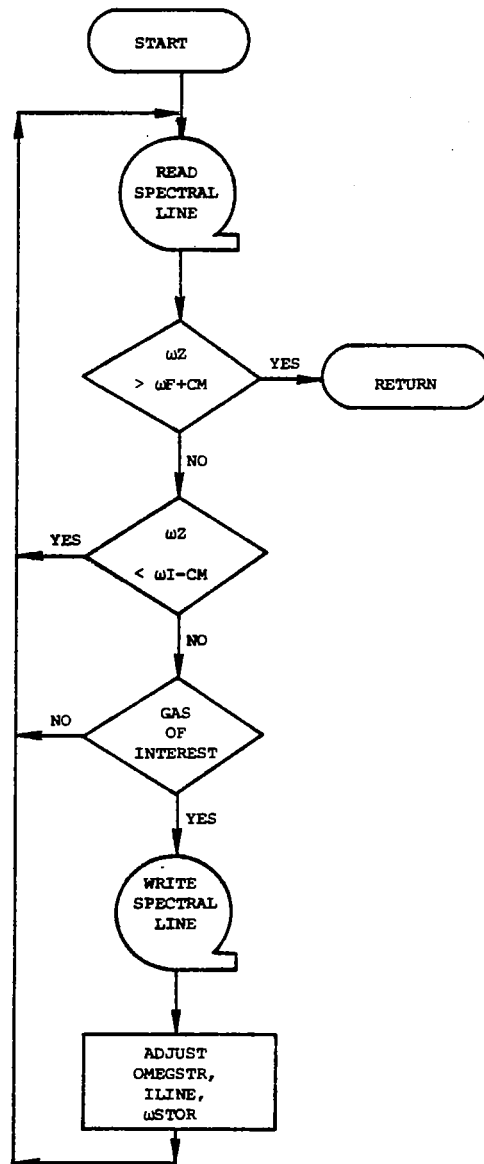


Figure 3. Flowchart of SMART program (continued).



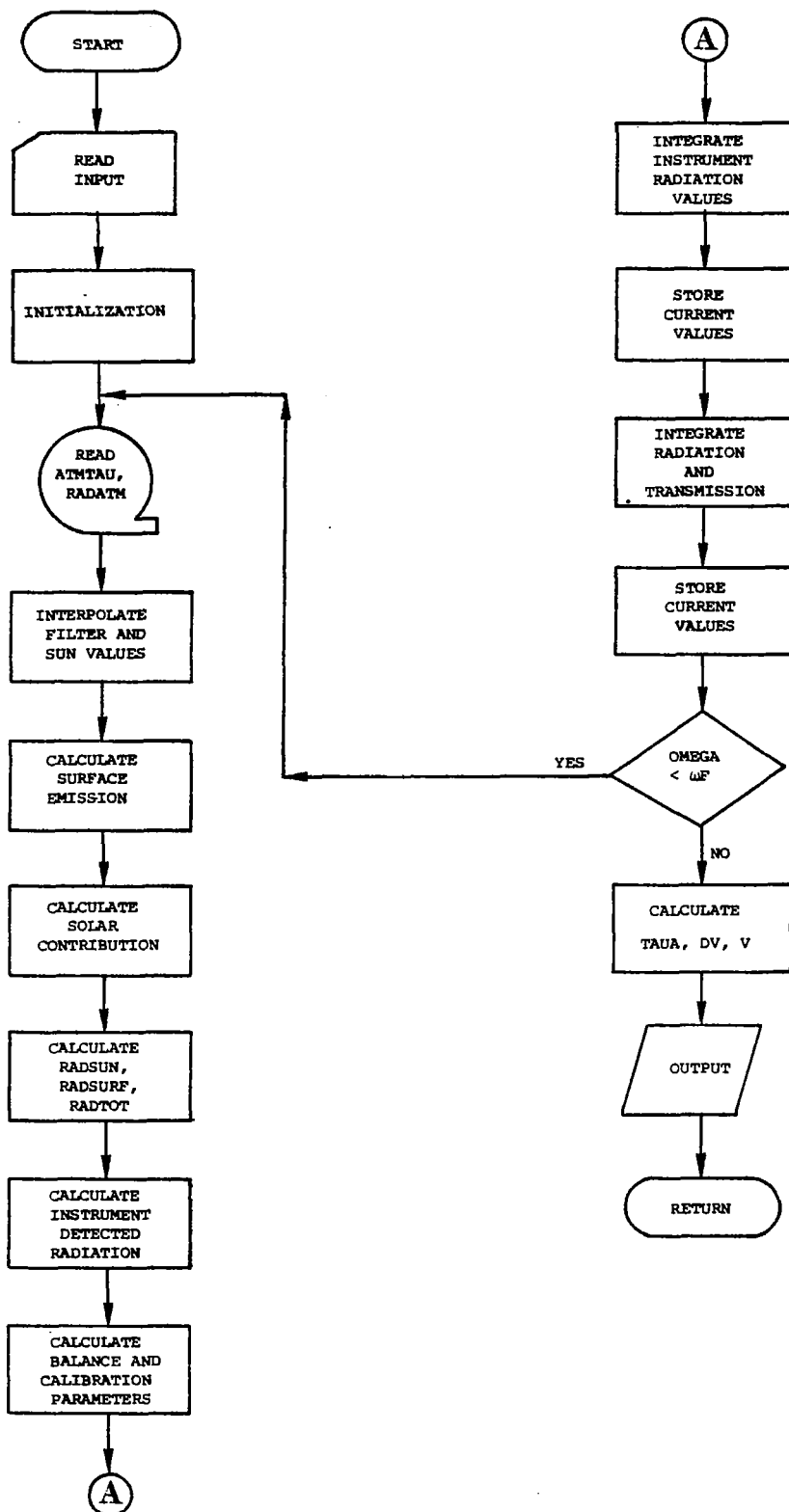


Figure 3. Flowchart of SMART program (continued).

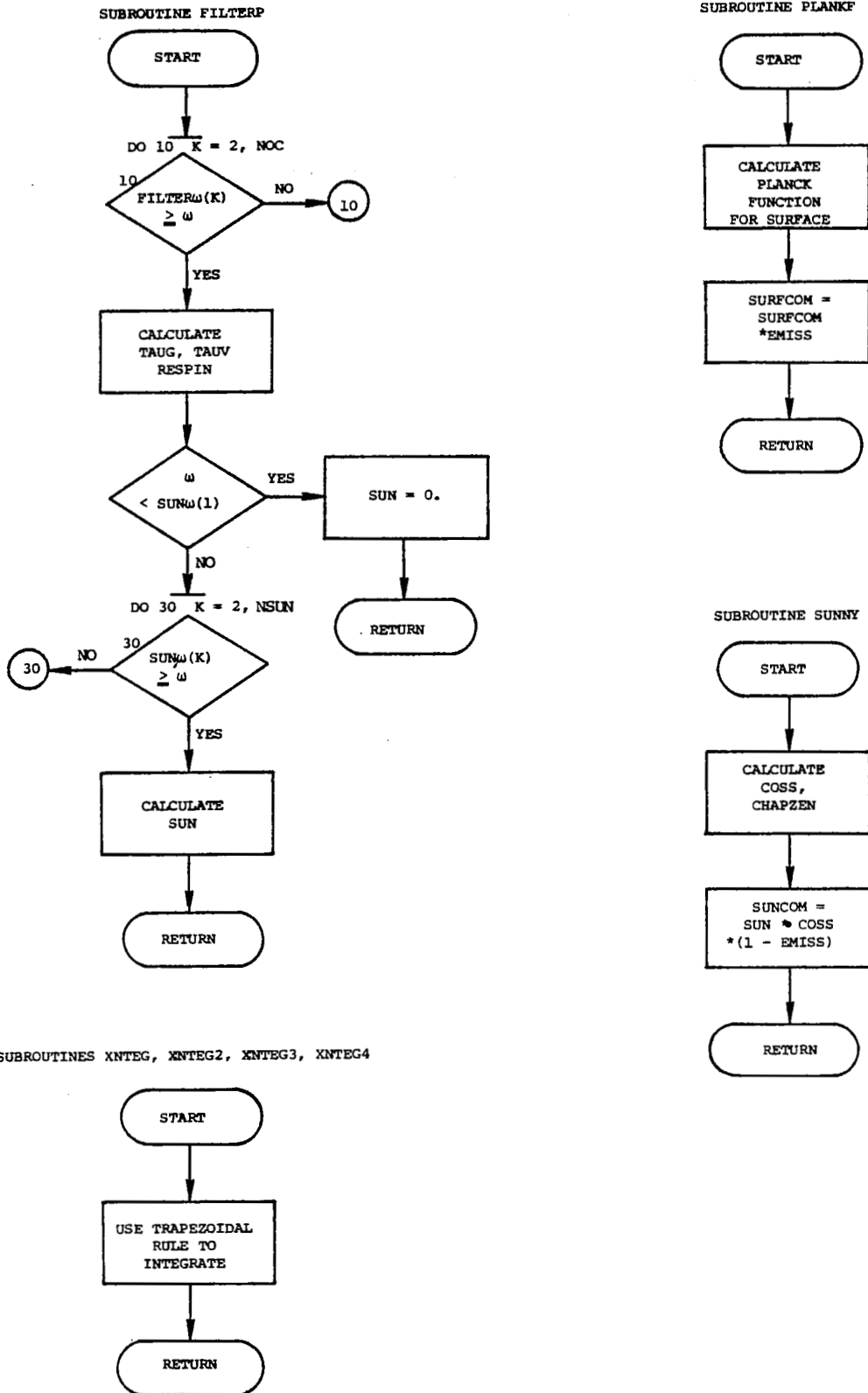


Figure 3. Flowchart of SMART program (concluded).

## PROGRAM SMART

SMART, the program executive, has two main functions. First, it supervises the execution of the two lower level overlays. Second, storage for each array and program constant, which is common to each overlay, is set aside. The storage required, i.e., program length + buffer length + labeled common length + blank common length, is 13241<sub>8</sub> .

```
1      OVERLAY(MAIN,0,0)
      PROGRAM SMART(INPUT,OUTPUT,TAPE7,TAPE2,TAPE6)
C *** THIS PROGRAM PERFORMS LINE-BY-LINE RADIATIVE TRANSFER CALCULATIONS FOR
C NON-HOMOGENEOUS ATMOSPHERIC MODELS AS A FUNCTION OF ALTITUDE
5 C *** THE SECOND SECTION SIMULATES THE RESPONSE OF THE GAS FILTER CORRELATION
C INSTRUMENT AT THE VARIOUS ALTITUDES ***
      COMMON/AB/TEMP(17),PRES(17),THICK(17),OPATH(17),GASCONC(20,17),
1      IDENT(20),XMULT(10),JPROF(17)
      COMMON/AA/NXH,NLAY,NLAYI,NOC,KBI,NSPEC,DELTAW,CHINV,IPOLLUT,
10      BROAD,WI,WF
      CALL OVERLAY(4HMAIN,1,0)
      REWIND 6
      CALL OVERLAY(4HMAIN,2,0)
15     STOP
      END
```

# PROGRAM TRANSMT

TRANSMT is the first overlay subordinate to SMART. TRANSMT reads the atmospheric profile information and the integration processing parameters from cards. From the spectral line parameter tape, wavenumbers, half-widths, intensities, energies of the lower state, and identification species numbers are read. For our calculations, McClatchey's spectral line parameter tape (ref. 5) was used with appropriate unit conversions applied. TRANSMT performs line-by-line radiative transfer calculations and writes on temporary storage disk 6 center wavenumber, transmittance, and radiance as a function of altitude and primary gas concentration. Storage required is 112274<sub>8</sub> .

```

1      OVERLAY(MAIN,1,0)
      PROGRAM TRANSMT
      DIMENSION REFTEMP(30),ALPHAL(300,17),PROFAC1(300,17),
1          PROFAC2(300,17),TAU(10),COMPABS(300,17),TINV(17),
5          1          ROOTEMP(17),ATMTAU(17,10),RADATH(17,10),
2          ALPHAV(300,17),RATLV(300,17),ALPHAD(300,17)
      REAL MOLWT(20),MOLWTIS
      COMMON/AB/TEMP(17),PRES(17),THICK(17),OPATH(17),GASCONC(20,17),
1          IDENT(20),XMULT(10),JPROF(17)
10     COMMON/AA/NXM,NLAY,NLAYI,NOC,KBI,NSPEC,DELTAW,CMINV,IPOLLUT,
1          BROAD,WI,WF
      COMMON WSTOR(300),OMEGSTR(300),ILINE(300)
      DATA C7/1.1906E-12/,C8/1.439/,C9/6.7675E-8/,C10/109./,NSUN/41/
      DATA (REFTEMP=30*296.)
15     DATA(MOLWT=28.,18.,64.,17.,16.,44.,44.,28.,17.,30.,46.,4*44.,64.,
1          46.,44.,17.,30.)
C ***INPUT PARAMETERS READ FROM CARDS ***
      READ 1010, NLAY,NLAYI,NOC,NXM,NSPEC,IDENT
1010  FORMAT(5I5,5X,20I2)
20     READ 1020,(JPROF(K),K=1,NLAY)
1020  FORMAT(40I2)
      READ 1030, WI,WF,DELTAW,CMINV,IPOLLUT,BROAD
1030  FORMAT(4F10.4,I5,F10.4)
      READ 1040, (XMULT(J),J=1,NXM)
25     1040  FORMAT(8F10.4)
      READ 1050, (TEMP(J),PRES(J),THICK(J),J=1,NLAY)
1050  FORMAT(3F10.4)
      READ 1060, ((GASCONC(J,K),J=1,16),K=1,NLAY)
1060  FORMAT(8E10.3)
30     C *** INITIALIZATION ***
      KBI=NLAY-2*NLAYI
      OMEGA=WI
      DW1=0.
      NSTORW=NOMEG=0
35     I=0

```

```

DO 10 K=1,NLAY
  OPATH(K)=PRES(K)* THICK(K)
  TINV(K)=1./TEMP(K)
  ROOTEMP(K)=SQRT(TEMP(K))
40  BRDFAC=(BROAD-1.)*GASCONC(IPOLLUT,K)+1.
  IF (NLAY.EQ.1) PRES(K)=PRES(K)*BRDFAC
  IF (K.GT.KBI) PRES(K)=PRES(K)*BRDFAC
10 CONTINUE
C *** READ SPECTRAL LINE PARAMETER TAPE FOR ALL LINES INCLUDED IN WI-CHINV TO
45  C
  WF +CMINV ***
  CALL READTP(WI,CHINV,WF,IDENT,NSTORW,NOMEG)
  20 W3=OMEGA *OMEGA *OMEGA
C *** DETERMINE SPECTRAL LINES TO BE INCLUDED IN SUBINTERVAL OF INTEGRATION
  C
50  AND ADJUST CORRESPONDING LINE PARAMETERS ***
  IF (OMEGA .EQ. WI) GO TO 50
  IF (OMEGSTR(1) .GE. (OMEGA-CHINV)) GO TO 45
  DO 25 K=2,NOMEG
    IPOINT=K
    IF (OMEGSTR(K) .GE. (OMEGA-CHINV)) GO TO 30
55  25 CONTINUE
  30 NOMEK=NOMEG -IPOINT +1
  I=I -IPOINT +1
  DO 35 J=1,NOMEK
    ILINE(J)=ILINE(J +IPOINT-1)
    OMEGSTR(J)=OMEGSTR(J +IPOINT-1)
60  35 CONTINUE
  DO 40 K=1,NLAY
    DO 40 J=1,NOMEK
      ALPHAL(J,K)=ALPHAL(J +IPOINT-1,K)
      PROFAC1(J,K)=PROFAC1(J +IPOINT-1,K)
      IF (JPROF(K).EQ.1) GO TO 40
      RATLV(J,K)=RATLV(J+IPOINT-1,K)
40  40 CONTINUE
45  IF (WZ .GT. (OMEGA +CMINV)) GO TO 100
  GO TO 65
70  50 I=0
C *** READ SPECTRAL LINES FOR SUBINTERVAL OF INTEGRATION ***
  REWIND 2
75  55 READ(2,1000) WZ,ALPHA,SZ,EL,IS
  1000 FORMAT(F10.4,F5.3,E15.8,F12.4,I2)
  IF (EOF(2)) 100,60
  60 IF (WZ .GT. (OMEGA +CMINV)) GO TO 100
  65 I=I+1
  IF (OMEGA .EQ. WI) GO TO 70
  NOMEK=NOMEG +1
  OMEGSTR(NOMEK)=WZ
  ILINE(NOMEK)=IS
  NSTORW=NSTORW +1
  WSTOR(NSTORW) =WZ
80  85 C *** DETERMINE LINE PROFILE PARAMETERS AND ADJUST FOR LAYER TEMPERATURE ***
  70 DO 95 K=1,NLAY
    TEMPCON=REFTEMP(IS) *TINV(K)
    TCONSO=TEMPCON *TEMPCON
    IF (IS .EQ. 2) TCONSO= TCONSO *SQRT(TEMPCON)
90  ADJALPH=ALPHA *PRES(K)* SQRT(TEMPCON)
    S=SZ *TCONSO *EXP(-C8 *(TEMPCON -1.) * EL/REFTEMP(IS))
    IF (JPROF(K).EQ.1) GO TO 85
    MOLWTIS=MOLWT(IS)
    ALPHAD(I,K)=C9*WZ*ROOTEMP(K)*SQRT(28./MOLWTIS)
    TSTALPH=ADJALPH/ALPHAD(I,K)
    ALPHAV(I,K)=.53431*ADJALPH+SQRT(.21687*ADJALPH*ADJALPH
1  + ALPHAD(I,K)*ALPHAD(I,K))
    VGTPAR=.83255*ADJALPH/ALPHAD(I,K)
    VGTPAR2=1./(VGTPAR*VGTPAR)
100  RATLV(I,K)=1./((1.+ADJALPH*VGTPAR2/ALPHAV(I,K))
    IF (VGTPAR.LT.1.5) GO TO 75
    VGTPAR4=VGTPAR2*VGTPAR2
    ERFC=(1.+4.5*VGTPAR2+2.*VGTPAR4)/(1.+5.*VGTPAR2
1  + 3.75*VGTPAR4)
    GO TO 80
105  75 TERFC=1./((1.+4.7047*VGTPAR)
    TERFC2=TERFC*TERFC
    ERFC=VGTPAR*TERFC*(.61686-.16994*TERFC+1.32554*TERFC2)

```

```

80  CONTINUE
110  85  ALPHAL(I,K)= ADJALPH
      IF (JPROF(K).EQ.2) GO TO 90
      PROFAC1(I,K)= .3183 *S/ADJALPH
      GO TO 95
      90  PROFAC1(I,K)=.3183*S*ERFC/ADJALPH
115  95  CONTINUE
      GO TO 55
C *** CALCULATE ABSORPTION COEFFICIENT AS DETERMINED BY LINE PROFILE ***
100  DO 120 K=1,NLAY
      DO 120 J=1,NOMEG
120    PROFAC2(J,K)=ABS(OMEGA- OMEGSTR(J))/ALPHAL(J,K)
      IF (JPROF(K).EQ.1) GO TO 115
      WRATLV=RATLV(I,K)
      WRATLV1=1.-WRATLV
125    FCL=1./(1.+(PROFAC2(J,K)*PROFAC2(J,K)))
      TSTPROF=ALPHAL(J,K)/ALPHAD(J,K)
      IF (TSTPROF.GT.1) GO TO 105
      EXPTST=-.693147*PROFAC2(J,K)*PROFAC2(J,K)
      IF (EXPTST.LT.-675.84) GO TO 105
      FCD=EXP(EXPTST)
130    GO TO 110
      105  FCD=0.
      110  FCERR=((1.8029/PROFAC2(J,K))-(1.4207*PROFAC2(J,K)))/
1      ((1./PROFAC2(J,K)) + (PROFAC2(J,K)*PROFAC2(J,K))*
135  2(.2030 + 1.07355*(PROFAC2(J,K)*PROFAC2(J,K))))
      FCV=WRATLV1*FCD+WRATLV*FCL+
1      WRATLV*WRATLV1*FCERR*(FCL - FCD)
      COMPABS(J,K)=GASCONC(ILINE(J),K)*FCV*PROFAC1(J,K)
      GO TO 120
115  CONTINUE
140  COMPABS(J,K)=GASCONC(ILINE(J),K)*PROFAC1(J,K)/(1.+PROFAC2(J,K)*
1      PROFAC2(J,K))
120  CONTINUE
      DO 125 K=1,NLAY
      DO 125 J=1,NXM
145    RADATM(K,J)=0.
      ATMTAU(K,J)=1.
125  CONTINUE
      DO 170 K=1,NLAY
      IF (K.EQ.1) GO TO 135
150    DO 130 J=1,NXM
      ATMTAU(K,J)=ATMTAU(K-1,J)
      RADATM(K,J)=RADATM(K-1,J)
130  CONTINUE
135  ABSCOF2=ABSCOF1+0.
      IF (K.LE.KBI) GO TO 145
155  DO 140 J=1,NXM
      ATMTAU(K,J)=1.
      RADATM(K,J)=0.
140  CONTINUE
160  DO 160 L=1,NOMEG
145    IF (ILINE(L).EQ. IPOLLUT) GO TO 150
      ABSCOF2= ABSCOF2 + COMPABS(L,K)
      GO TO 155
150    ABSCOF1=ABSCOF1 +COMPABS(L,K)
165  155  CONTINUE
160  CONTINUE
      PLANCK=C7*W3/(EXP(C8*OMEGA/TEMP(K))-1.)
      ABSCOF1=ABSCOF1 +ABSCOF2
C *** CALCULATE MONOCHROMATIC ATMOSPHERIC TRANSMITTANCE AND EMISSION AND WRITE
170  C  RESULTS ON DISC 6 ***
      DO 165 J=1,NXM
      IF (K.LE.KBI) ABSCOF1= ABSCOF1 *XMULT(J) +ABSCOF2
      TAU(J)= EXP(-ABSCOF1 *OPATH(K))
      RADATM(K,J)=RADATM(K,J)*TAU(J)+PLANCK*(1.-TAU(J))
175  ATMTAU(K,J)=ATMTAU(K,J)*TAU(J)
165  CONTINUE
170  CONTINUE
      WRITE(6)OMEGA,((ATMTAU(K,J),J=1,NXM),K=1,NLAY),((RADATM(K,J),
1      J=1,NXM),K=1,NLAY),DW1
180  C *** CALCULATE NEW OMEGA ***
      CALL GETW(OMEGA,DELTAH,NSTORW,DW1)
      IF (OMEGA .LE. WF) GO TO 20
      RETURN
      END

```

# SUBROUTINE GETW

GETW is a subroutine of TRANSMT. GETW determines the wavenumber mesh for integration. The algorithm 1) determines the distance from OMEGA to the closest spectral line, 2) calculates  $1/4$  of that distance, 3) determines the maximum (DW) between DWMIN and the value calculated in step 2, and 4) sets the new integration point equal to OMEGA plus DW. The minimum integration stepping size is read in TRANSMT. Storage required is 1644<sub>8</sub> .

```

1      SUBROUTINE GETW(W,DW,NSTORW,DW1)
      C *** DETERMINE THE WAVENUMBER MESH FOR INTEGRATION ***
      COMMON WSTOR(300),OMEGSTR(300),ILINE(300)
      W1=W-WSTOR(1)
5      W2=WSTOR(2)-W
      DW1=AMAX1(AMIN1(W1,W2)*.25,DW)
      W=W +DW1
      IF (WSTOR(2) .GT. W) RETURN
      K=3
10     IF (WSTOR(K).GT.W) GO TO 10
      K=K+1
      GO TO 5
10    NSTORW=NSTORW-K+2
      DO 15 J=1,NSTORW
15    WSTOR(J)=WSTOR(J+K-2)
      RETURN
      END

```

# SUBROUTINE READTP

READTP is a subroutine of TRANSMT. READTP reads the spectral line parameter tape for all lines in the interval  $WI - CMINV$  to  $WF + CMINV$  and writes them on temporary storage disk 2. Storage required is 2000<sub>8</sub> .

```

1      SUBROUTINE READTP(WI,CM,WF,IDENT,K,L)
C *** READ SPECTRAL LINE PARAMETER TAPE FOR ALL LINES FROM WI-CMINV TO WF +
C      CMINV
C      VARIABLES INCLUDE LINE LOCATION (WZ), HALF-WIDTH (BL), LINE STRENGTH (S),
5      C      GROUND STATE ENERGY (E), SPECIES IDENTIFICATION NUMBER (IS) ***
C      DIMENSION IDENT(20)
C      COMMON WSTOR(300), OMEGSTR(300), ILINE(300)
C      REWIND 2
C      K=1
10     L=0
C      5 READ(7,1000) WZ,BL,S,E,IS
C      IF (WZ .GT. (WF +CM)) GO TO 25
C      IF (WZ .LT. (WI- CM)) GO TO 5
C      DO 10 J= 1,16
15     IF (IDENT(J) .EQ. IS) GO TO 15
C      10 CONTINUE
C      GO TO 5
C      15 WRITE(2,1000) WZ,BL,S,E,IS
C      PRINT 1010, WZ,BL,S,E,IS
20     1010 FORMAT(1H ,F10.4,1X,F5.3,1X,E15.8,1X,F12.4,1X,I2)
C      IF (WZ .LT. WI) WSTOR(1)=WZ
C      IF (WZ .GT. (WI +CM)) GO TO 5
C      L= L+1
C      ILINE(L)=IS
25     OMEGSTR(L)= WZ
C      20 IF (WZ.LT.WI) GO TO 5
C      K=K +1
C      WSTOR(K) =WZ
C      GO TO 5
30     1000 FORMAT(F10.4,F5.3,E15.8,F12.4,I2)
C      25 WRITE(2,1000)WZ,BL,S,E,IS
C      RETURN
C      END

```



# PROGRAM SRTGFCA

SRTGFCA is the second overlay subordinate to SMART. SRTGFCA reads from cards surface temperatures and emissivities, and optical and thermal parameters as required for instrument simulation. SRTGFCA reads from temporary storage disk 6 the transmittance and radiance calculations performed by TRANSMT, and computes instrument response parameters. It is again emphasized that any infrared instrument requiring atmospheric transmittance and radiance information as input may be substituted for SRTGFCA. Storage required is 27342, .

```

1      OVERLAY(MAIN,2,0)
      PROGRAM SRTGFCA
      DIMENSION ATMTAU(17,10),RADATH(17,10),RADSUM(10,2,10),TAUSLAT(10),
5      1      SUNCOM(10),RADSURF(100,2,2),SURFCOM(10,10),
      2      RADTOT(100,2,2),SUNW(41),SUNFLUX(41),CONC1(10),
      3      CONC(10),ID(10)
      DIMENSION PLANK(10),BLCKIN(10),VACBNEW(10),GASBNEW(10),BBHNEW(10),
10      1      GASANEW(100,2,2),VACANEW(100,2,2),GASENEW(100,2,2),
      2      BBCNEW(10),BBHOT(10),BBCOLD1(10),BBHNEWG(10),BBCNEWG(10)
      3      ,BBHNEWC(10),BBCNEWC(10),BBHNEWV(10),BRCNEWV(10),
      4      BBHOLD(10),BBCOLD(10),BBHOLDG(10),BBCOLDG(10),
      5      BBHOLDC(10),BBCOLDC(10),VACBOLD(10),GASBOLD(10),
      6      GASBOLD(100,2,2),VACBOLD(100,2,2),GASEOLD(100,2,2),
      7      RADHOT(10),RADCOLD(10),RADHOTG(10),RADCOLG(10),
15      8      RADHOTC(10),RADCOLC(10),RADVACB(10),RADGASB(10),
      9      RADGASA(100,2,2),RADVACA(100,2,2),RADGASE(100,2,2),
      A      BBHOLDV(10),BBCOLDV(10),RADHOTV(10),RADCOLV(10)
      DIMENSION TOTSUM(10,2,10),TOTSURF(100,2,2),RADSUM(10,2,10),
20      1      TOTRAD(100,2,2),RADSOLD(100,2,2),RADOLD(17,10),
      2      RADTOT(100,2,2),TAUOLD(17,10),TRANS(17,10),TOTATH(17,10)
      3      ,GBALDIF(10),VBALDIF(10),TAUA(10),SIGRV(10),
      4      GCLTAIN(10),ERRDN(10),SIGAV(100,2,2),DV(100,2,2),
      5      GCLTAAT(100,2,2),V(100,2,2)
      COMMON/AB/TEMP(17),PRES(17),THICK(17),OPATH(17),GASCONC(20,17),
25      1      IDENT(20),XMULT(10),JPROF(17)
      COMMON/AA/NXM,NLAY,NLAYI,NOC,KBI,NSPEC,DELTAW,CMINV,IPOLLUT,
      1      BROAD,WI,Wf
      COMMON/CA/RESP6(35),FILTERW(35),RESPV(35),RESP(35)
      COMMON/CB/EMISS(10),TSURF(10)
30      DATA(SUNW=1941.75,1980.20,2020.20,2061.86,2105.26,2150.54,2197.80,
      1      2247.19,2298.85,2352.94,2409.64,2469.14,2531.64,2597.40,
      2      2666.67,2739.73,2816.90,2898.55,2985.07,3076.92,3174.60,
      3      3278.69,3389.83,3508.77,3636.36,3773.58,3921.57,4081.63,
      4      4255.32,4444.44,4651.16,4878.05,5128.21,5405.41,5714.29,
35      6060.61,6451.61,6896.55,7407.41,8000.00,8695.65)
      DATA(SUNFLUX=.274E-6,.284E-6,.296E-6,.307E-6,.323E-6,.330E-6,
      1      .343E-6,.359E-6,.362E-6,.391E-6,.411E-6,.439E-6,
      2      .462E-6,.481E-6,.501E-6,.526E-6,.554E-6,.580E-6,
      3      .607E-6,.639E-6,.673E-6,.708E-6,.748E-6,.789E-6,
40      4      .835E-6,.883E-6,.938E-6,.995E-6,1.058E-6,1.128E-6,
      5      1.204E-6,1.286E-6,1.376E-6,1.474E-6,1.581E-6,
      6      1.699E-6,1.826E-6,1.964E-6,2.110E-6,2.250E-6,

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```

7          2.322E-6)
DATA C7/1.1906E-12/,C8/1.439/,C9/6.7675E-8/,C10/109./,NSUN/41/
45 READ 1080,NEMIS,NSURF,NOC,ZENITH
1080 FORMAT(3I5,F10.3)
READ 1090,(TSURF(J),J=1,NSURF)
1090 FORMAT(8E10.3)
READ 1090,(EMISS(J),J=1,NEMIS)
50 READ 1100,(FILTERW(J),RESPV(J),RESPG(J),RESP(J),J=1,NOC)
1100 FORMAT(F10.3,F10.6,F10.6,F10.3)
READ 1090,(BLCKIN(K),K=1,NLAYI)
READ 1090,(BBHOT(K),BBCOLD(K),K=1,NLAYI)
READ 1090, EMISBB
55 IF ((WI.LT.FILTERW(1)).OR.(WF.GT.FILTERW(NOC))) GO TO 500
JCOUNT=0
DO 5 K=1,NLAY
DO 5 J=1,NXM
RADATM(K,J)=TRANS(K,J)=TOTATM(K,J)=0.
60 5 CONTINUE
DO 10 K=1,NLAYI
RADHOT(K)=RADCOLD(K)=RADHOTG(K)=RADCOLG(K)=RADHOTC(K)=RADCOLC(K)=
1 RADVACB(K)=RADGASB(K)=RADHOTV(K)=RADCOLV(K)=0.
10 CONTINUE
DO 15 K=1,NLAY
DO 15 L=1,NEMIS
DO 15 M=1,NSURF
DO 15 J=1,NXM
TOTSUN(K,L,J)=0.
70 JJ=J+(K-1)*10
RADGASA(JJ,L,M)=RADVACA(JJ,L,M)=RADGASE(JJ,L,M)=0.
TOTRAD(JJ,L,M)=TOTSURF(JJ,L,M)=0.
15 CONTINUE
C *** READ DISC 6 ***
75 20 READ(6)OMEGA,((ATMTAU(K,J),J=1,NXM),K=1,NLAY),((RADATM(K,J),
1 J=1,NXM),K=1,NLAY),DW1
IF (EOF(6)) 185,25
25 JCOUNT=JCOUN+1
C *** INTERPOLATE WAVENUMBER DEPENDENT INPUT VALUES ***
80 CALL FILTERP(OMEGA,TAUVFIL,TAUGFIL,SUNINTP,NOC,NSUN,SUNW,SUNFLUX,
1RESPIN)
C ***CALCULATE UNATTENUATED SURFACE EMISSION ***
CALL PLANKF(OMEGA,SURFCOM,NEMIS,NSURF)
C *** CALCULATE UNATTENUATED SOLAR RADIATION REFLECTED BY THE EARTH SURFACE ***
85 IF (ZENITH.GE.90.) GO TO 30
CALL SUNNY(OMEGA,NEMIS,SUNCOM,ZENITH,SUNINTP,CHAPZEN)
GO TO 40
30 CHAPZEN=0.
DO 35 L=1,NEMIS
90 35 SUNCOM(L)=0.
C *** CALCULATE TOTAL ATTENUATED RADIATION AT THE TOP OF EACH ATMOSPHERIC
C LAYER ***
40 DO 130 K=1,KBI
DO 130 L=1,NEMIS
95 DO 130 M=1,NSURF
DO 130 J=1,NXM
JJ=J+(K-1)*10
TAUSLAT(J)=ATMTAU(KBI,J)**CHAPZEN
RADTUN(K,L,J)=SUNCOM(L)*TAUSLAT(J)* ATMTAU(K,J)
100 RADSURF(JJ,L,M)=SURFCOM(L,M)* ATMTAU(K,J)
RADTOT(JJ,L,M)=RADATM(K,J) + RADSURF(JJ,L,M) + RADTUN(K,L,J)
130 CONTINUE
IF (NLAYI.EQ.0) GO TO 160
W3= OMEGA *OMEGA *OMEGA
105 C *** CALCULATE INSTRUMENT DETECTED RADIATION ***
DO 140 K=1,NLAYI
PLANK(K) =C7 *W3/(EXP(C8 *OMEGA/BLCKIN(K))-1.) *EMISBB
VACBNEW(K) =PLANK(K)*TAUVFIL *RESPIN
GASBNEW(K) =PLANK(K)*ATMTAU(K+KBI,1) *TAUGFIL *RESPIN
110 DO 135 L=1,NEMIS
DO 135 M=1,NSURF
DO 135 J=1,NXM

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      JJ=J +(K-1) *10
      GASANEW(JJ,L,M)=RADTOT(JJ,L,M) *ATMTAU(K+KBI,1) *TAUGFIL*RESPIN
115  VACANEW(JJ,L,M)=RADTOT(JJ,L,M) *TAUVFIL *RESPIN
      GASENEW(JJ,L,M)=(RADTOT(JJ,L,M) *ATMTAU(K+KBI,1) +RADATM(K+KBI,
      1)) *TAUGFIL*RESPIN
135 1 CONTINUE
C *** CALCULATE BALANCE AND CALIBRATION PARAMETERS ***
120 BBHNEW(K)=(C7 *W3/(EXP(C8 *OMEGA/BBHOT(K))-1.)) *TAUVFIL *RESPIN
      BBCNEW(K)=(C7 *W3/(EXP(C8 *OMEGA/BBCOLD1(K))-1.)) *TAUVFIL*RESPIN
      BBHNEWG(K)=(C7*W3/(EXP(C8*OMEGA/BBHOT(K))-1.))*ATMTAU(K+KBI,1)*
      1 TAUGFIL*RESPIN
      BBCNEWG(K)=(C7*W3/(EXP(C8*OMEGA/BBCOLD1(K))-1.))*ATMTAU(K+KBI,1)*
125 1 TAUGFIL*RESPIN
      BBHNEWC(K)=BBHNEWG(K)*ATMTAU(K+KBI+NLAYI,1)+(RADATM(K+KBI+NLAYI,1)
      * TAUGFIL*RESPIN)*ATMTAU(K+KBI,1)
      BBCNEWC(K)=BBCNEWG(K)*ATMTAU(K+KBI+NLAYI,1)+(RADATM(K+KBI+NLAYI,1)
      * TAUGFIL*RESPIN)*ATMTAU(K+KBI,1)
130 BBHNEWV(K)=BBHNEW(K)*ATMTAU(K+KBI+NLAYI,1)+(RADATM(K+KBI+NLAYI,1)
      * TAUVFIL*RESPIN)
      BBCNEWV(K)=BBCNEW(K)*ATMTAU(K+KBI+NLAYI,1)+(RADATM(K+KBI+NLAYI,1)
      * TAUVFIL*RESPIN)
140 140 CONTINUE
      IF (OMEGA.EQ.WI) GO TO 145
135 C *** INTEGRATE INSTRUMENT RADIATION VALUES ***
      CALL XNTEG(DW1,BBHNEW,BBHOLD,RADHOT,NLAYI)
      CALL XNTEG(DW1,BBCNEW,BBCOLD,RADCOLD,NLAYI)
      CALL XNTEG(DW1,BBHNEWG,BBHOLDG,RADHOTG,NLAYI)
140 CALL XNTEG(DW1,BBCNEWG,BBCOLDG,RADCOLDG,NLAYI)
      CALL XNTEG(DW1,BBHNEWC,BBHOLDC,RADHOTC,NLAYI)
      CALL XNTEG(DW1,BBCNEWC,BBCOLDC,RADCOLD,C,NLAYI)
      CALL XNTEG(DW1,VACBNEW,VACBOLD,RADVACB,NLAYI)
      CALL XNTEG(DW1,GASBNEW,GASBOLD,RADGASB,NLAYI)
145 CALL XNTEG(DW1,BBHNEWV,BBHOLDV,RADHOTV,NLAYI)
      CALL XNTEG(DW1,BBCNEWV,BBCOLDV,RADCOLDV,NLAYI)
      CALL XNTEG2(DW1,GASANEW,GASOLD,RADGASA,NLAYI,NEMIS,NSURF,NXM)
      CALL XNTEG2(DW1,VACANEW,VACOLD,RADVACA,NLAYI,NEMIS,NSURF,NXM)
      CALL XNTEG2(DW1,GASENEW,GASEOLD,RADGASE,NLAYI,NEMIS,NSURF,NXM)
150 C *** STORE CURRENT INSTRUMENT RADIATION VALUES FOR INTEGRATION PURPOSES ***
      145 DO 155 K=1,NLAYI
          BBHOLD(K)=BBHNEW(K)
          BBCOLD(K)=BBCNEW(K)
          BBHOLDG(K)=BBHNEWG(K)
155 BBCOLDG(K)=BBCNEWG(K)
          BBHOLDC(K)=BBHNEWC(K)
          BBCOLDC(K)=BBCNEWC(K)
          BBHOLDV(K)=BBHNEWV(K)
          BBCOLDV(K)=BBCNEWV(K)
160 VACBOLD(K)=VACBNEW(K)
          GASBOLD(K)=GASBNEW(K)
          DO 150 L=1,NEMIS
              DO 150 M=1,NSURF
                  DO 150 J=1,NXM
                      JJ= J+(K-1) *10
                      GASOLD(JJ,L,M)=GASANEW(JJ,L,M)
                      VACOLD(JJ,L,M)=VACANEW(JJ,L,M)
                      GASEOLD(JJ,L,M)=GASENEW(JJ,L,M)
150 150 CONTINUE
170 155 CONTINUE
      160 IF (OMEGA.EQ.WI) GO TO 165
C *** INTEGRATE ATMOSPHERIC RADIATION AND TRANSMITTANCE AND INSTRUMENT
C TRANSMITTANCE ***
175 CALL XNTEG3(DW1,ATMTAU,TAUOLD,TRANS,NLAY,NXM)
      CALL XNTEG3(DW1,RADATM,RADOLD,TOTATM,NLAY,NXM)
      CALL XNTEG2(DW1,RADTOT,RADTOT,TOTRAD,KBI ,NEMIS,NSURF,NXM)
      CALL XNTEG2(DW1,RADSURF,RADSOLD,TOTSURF,KBI ,NEMIS,NSURF,NXM)
      CALL XNTEG4(DW1,RADSUN,RADSUN,TOTSUN,KBI ,NEMIS,NXM)
C *** STORE CURRENT TRANSMISSION AND ATMOSPHERIC RADIATION VALUES FOR
180 C INTEGRATION PURPOSES ***
      165 DO 170 K=1,NLAY
          DO 170 J=1,NXM

```

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        TAUOLD(K,J)=ATMTAU(K,J)
        RADOLD(K,J)=RADATM(K,J)
185      170 CONTINUE
        DO 180 K=1,KBI
        DO 175 L=1,NEMIS
        DO 175 M=1,NSURF
        DO 175 J=1,NXM
190      JJ=J+(K-1)*10
        RADTOT(JJ,L,M)=RADTOT(JJ,L,M)
        RADSOLD(JJ,L,M)=RADSURF(JJ,L,M)
        RADSUND(K,L,J)=RADSUN(K,L,J)
        175 CONTINUE
195      180 CONTINUE
        GO TO 20
C *** CALCULATE INSTRUMENT OUTPUT RESPONSE PARAMETERS ***
185      IF (NLAYI.EQ.0) GO TO 200
        DO 195 K=1,NLAYI
200      GBALDIF(K)=RADHOTG(K)-RADCOLG(K)
        VBALDIF(K)=RADHOJ(K)-RADCOLD(K)
        TAU(K)=GBALDIF(K)/VBALDIF(K)
        SIGBV(K)=RADVACB(K)*TAU(K)
        GCLTAIN(K)=RADGASB(K)/RADVACB(K)
205      ERRDN(K)=RADGASB(K)-TAU(K)*RADVACB(K)
        DO 190 L=1,NEMIS
        DO 190 M=1,NSURF
        DO 190 J=1,NXM
        JJ=J+(K-1)*10
210      SIGAV(JJ,L,M)=RADVACA(JJ,L,M)*TAU(K)
        DV(JJ,L,M)=RADGASA(JJ,L,M)-SIGAV(JJ,L,M)
        GCLTAAT(JJ,L,M)=RADGASA(JJ,L,M)/RADVACA(JJ,L,M)
        V(JJ,L,M)=(RADGASA(JJ,L,M)+SIGAV(JJ,L,M))/2.
        190 CONTINUE
215      195 CONTINUE
C *** OUTPUT ***
200      J=0
        DO 250 LL=1,16
        IF (IDENT(LL).EQ.0) GO TO 250
220      J=J+1
        IF (IDENT(LL).EQ.1) ID(J)=2HCO
        IF (IDENT(LL).EQ.2) ID(J)=3HH2O
        IF (IDENT(LL).EQ.7) ID(J)=3HN2O
        IF (IDENT(LL).EQ.12) ID(J)=3HCO2
225      250 CONTINUE
        IF (IPOLLUT.EQ.1) IPOLT=2HCO
        IF (IPOLLUT.EQ.2) IPOLT=3HH2O
        IF (IPOLLUT.EQ.3) IPOLT=3HSO2
        IF (IPOLLUT.EQ.4) IPOLT=3HNH3
230      IF (IPOLLUT.EQ.5) IPOLT=3HCH4
        IF (IPOLLUT.EQ.7) IPOLT=3HN2O
        IF (IPOLLUT.EQ.12) IPOLT=3HCO2
        C=2.*CMINV
        DIST=WF-WI
235      DO 255 K=1,NLAY
        DO 255 J=1,NXM
        TRANS(K,J)=TRANS(K,J)/DIST
        255 CONTINUE
        PRINT 2000,IPOLT,WI,WF,C,DELTAW,JCOUNT
240      2000 FORMAT(1H1,*THE INVESTIGATED POLLUTANT IS *,A3/* THE WAVENUMBER IN
        INTERVAL IS *,F10.3,* TO *,F10.3/* THE SUBINTERVAL OF INTEGRATION IS
        2 *,F10.3,* CM-1/* THE MINIMUM INTEGRATING INCREMENT IS *,F6.3,* C
        3M-1/* THE NUMBER OF POINTS OF INTEGRATION IS *,I6)
        PRINT 2010
245      2010 FORMAT(1H0,*FILTER FUNCTION*/ * WAVENUMBER VACUUM RESP GAS CELL
        1 RESP DETECTOR RESP*)
        PRINT 2020,(FILTERW(J),RESPV(J),RESPG(J),RESP(J),J=1,NOC)
250      2020 FORMAT(1H ,F10.3,4X,F10.4,4X,F10.4,6X,F10.4)
        DO 300 J=1,NXM
        CONC1(J)=XMULT(J)*GASCONC(IPOLLUT,1)
250      300 CONTINUE
        PRINT 2030

```

```

2030 FORMAT(1H1,*ATMOSPHERIC PARAMETERS*)
      PRINT 2040,(ID(J),J=1,NSPEC)
255 2040 FORMAT(1H,*LAYER TEMP (K) PRESS (ATM) THICK (CM) PATH (ATM-CM
      1) *,4(A3,8X))
      DO 310 K=1,NLAY
        BRDFAC=(BROAD-1.) *GASCONC(IPOLLUT,1) +1.
        IF (K.LE.KBI) PRES(K)=PRES(K) *BRDFAC
        IF (K.GT.KBI) PRES(K)=PRES(K)/BRDFAC
260 310 CONTINUE
      DO 330 K=1,NLAY
        J=0
        DO 320 LL=1,16
          IF (IDENT(LL).EQ. 0) GO TO 320
          J=J+1
          CONC(J)=GASCONC(IDENT(LL),K)
265 320 CONTINUE
      PRINT 2050,K,TEMP(K),PRES(K),THICK(K),OPATH(K),(CONC(J),J=1,NSPEC)
270 2050 FORMAT(1H ,I2,5X,F7.2,3X,F8.5,5X,1PE12.5,1X,E12.5,3X,4(E10.3,1X))
      330 CONTINUE
      PRINT 2060,ZENITH
2060 FORMAT(1H0,*THE SUN ZENITH ANGLE IS *,OPF7.3,* DEGREES*)
      LOOP=NLAY
275 IF (NLAYI.GT.0) LOOP=NLAYI
      DO 400 K=1,LOOP
        PRINT 2070,K
2070 FORMAT(1H1,*LAYER *,I2)
        IF (JPROF(K).EQ.1) IPROF=7HLORENTZ
        IF (JPROF(K).EQ.2) IPROF=5HVOIGT
        PRINT 2075, IPROF
280 2075 FORMAT(1H ,*THE SPECTRAL LINE PROFILE IS *,A7)
        PRINT 2080
2080 FORMAT(1H0,*ATMOSPHERIC OUTPUT PARAMETERS*)
285 PRINT 2090,(CONC1(J),J=1,NXM)
2090 FORMAT(1H ,*THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSI
      1DERED ARE*/10X,1P10E12.4)
        PRINT 2100,(TRANS(K,J),J=1,NXM),(TOTATM(K,J),J=1,NXM)
290 2100 FORMAT(1H ,*TRANS  ***,1P10E12.4,/* TOTATM  ***,10E12.4)
        DO 340 L=1,NEMIS
          PRINT 2110,EMISS(L)
2110 FORMAT(1H ,*SURFACE EMISSIVITY ***,OPF6.3)
          PRINT 2120,(TOTSUN(K,L,J),J=1,NXM)
2120 FORMAT(1H ,*TOTSUN  ***,1P10E12.4)
295 340 CONTINUE
        JJ=1+(K-1)*10
        JK=JJ+9
        DO 350 L=1,NEMIS
          DO 350 M=1,NSURF
300 PRINT 2130,EMISS(L),TSURF(M)
2130 FORMAT(1H ,*SURFACE EMISSIVITY = *,OPF6.3,/* SURFACE TEMPERATURE =
      1 *,F8.3)
          PRINT 2140,(TOTSURF(J,L,M),J=JJ,JK),(TOTRAD(J,L,M),J=JJ,JK)
305 2140 FORMAT(1H ,*TOTSURF ***,1P10E12.4,/* TOTRAD  ***,10E12.4)
          350 CONTINUE
          IF (NLAYI.EQ.0) GO TO 400
          PRINT 2150
2150 FORMAT(1H0,*INSTRUMENT OUTPUT PARAMETERS*)
          PRINT 2160,RADVACB(K),RADGASB(K),TAUA(K),ERRDN(K)
310 2160 FORMAT(1H ,*RADVACB ***,1PE12.4,/* RADGASB ***,E12.4/* TAUA  ***,E
      112
      1.4/* ERRDN  ***,E12.4)
          PRINT 2090,(CONC1(J),J=1,NXM)
          PRINT 2170,(TRANS(K+KBI,J),J=1,NXM)
315 2170 FORMAT(1H ,*TRANS  ***,1P10E12.4)
          DO 360 L=1,NEMIS
            DO 360 M=1,NSURF
              PRINT 2130,EMISS(L),TSURF(M)
              PRINT 2180,(RADVACA(J,L,M),J=JJ,JK),(RADGASA(J,L,M),J=JJ,JK),
              1(RADGASE(J,L,M),J=JJ,JK),(DV(J,L,M),J=JJ,JK),(V(J,L,M),J=JJ,JK)
320 2180 FORMAT(1H ,*RADVACA ***,1P10E12.4/* RADGASA ***,10E12.4/* RADGASE **
      1,10E12.4/* DV  ***,10E12.4/* V  ***,10E12.4)
          360 CONTINUE
          PRINT 2190

```

```

325 2190 FORMAT(1H0,*CALIBRATION OUTPUT PARAMETERS*)
      DVHOT=RADHOTC(K)-TAUA(K)*RADHOTV(K)
      DVCOLD=RADCOLC(K)-TAUA(K)*RADCOLV(K)
      VHOT=(RADHOTC(K) + TAUA(K)*RADHOTV(K))/2.
      VCOLD=(RADCOLC(K) +TAUA(K)*RADCOLV(K))/2.
330 PRINT 2200, TRANS(K+KBI+NLAYI,1),RADHOTC(K),RADCOLC(K),RADHOTV(K),
      1RADCOLV(K),DVHOT,DVCOLD,VHOT,VCOLD
2200 FORMAT(1H,*TRANS ** ,1PE12.4,/* RADHOTC ** ,E12.4,/* RADCOLC ** ,
      1E12.4,/* RADHOTV ** ,E12.4,/* RADCOLV ** ,E12.4,/* DVHOT ** ,E12.4,
      2/* DVCOLD ** ,E12.4,/* VHOT ** ,E12.4,/* VCOLD ** ,E12.4)
335 PRINT 2210
2210 FORMAT(1H,*BALANCE OUTPUT PARAMETERS*)
      DVHOTB=RADHOTG(K)-TAUA(K)*RADHOT(K)
      DVCOLDB=RADCOLG(K)-TAUA(K)*RADCOLD(K)
      VHOTB=(RADHOTG(K) +TAUA(K)*RADHOT(K))/2.
340 VCOLDB=(RADCOLG(K) +TAUA(K)*RADCOLD(K))/2.
      PRINT 2220,RADHOT(K),RADCOLD(K),RADHOTG(K),RADCOLG(K),DVHOTB,
      1DVCOLDB,VHOTB,VCOLDB
2220 FORMAT(1H,*RADHOT ** ,1PE12.4,/* RADCOLD ** ,E12.4,/* RADHOTG ** ,
      1E12.4,/* RADCOLG ** ,E12.4,/* DVHOTB ** ,E12.4,/* DVCOLDB ** ,E12.4,
      2/* VHOTB ** ,E12.4,/* VCOLDB ** ,E12.4)
345 400 CONTINUE
      GO TO 550
      500 PRINT 3000
350 3000 FORMAT(1H1,*THE WAVENUMBER INTERVAL IS OUTSIDE OF THE FILTER RANGE
      1*)
      550 RETURN
      END

```

# SUBROUTINE FILTERP

FILTERP is a subroutine of SRTGFCA. FILTERP interpolates linearly the wavenumber-dependent vacuum cell and gas cell filter transmission, detector response, and solar flux values. Input filter parameters are read from cards in SRTGFCA while solar flux parameters are found in DATA statements in SRTGFCA. Storage required is 272, .

```

1      SUBROUTINE FILTERP(W,TAUV,TAUG,SUN,NOC,NSUN,SUNW,SUNFLUX,RESPIN)
C *** INTERPOLATE WAVENUMBER DEPENDENT VACUUM CELL RESPONSE, GAS CELL RESPONSE,
C *** DETECTOR RESPONSE, AND SOLAR FLUX FROM INPUTTED PARAMETERS ***
      DIMENSION SUNW(41),SUNFLUX(41)
      COMMON/CA/RESPG(35),FILTERW(35),RESPV(35),RESP(35)
5      DO 10 K=2,NOC
          K2=K
          IF (FILTERW(K).GE.W) GO TO 20
10     CONTINUE
      20 K1=K2-1
          COM=(W-FILTERW(K1))/(FILTERW(K2)-FILTERW(K1))
          RESPIN=RESP(K1)+ COM*(RESP(K2)-RESP(K1))
          TAUV=RESPV(K1)+COM*(RESPV(K2)-RESPV(K1))
          TAUG=RESPG(K1)+COM*(RESPG(K2)-RESPG(K1))
15     IF (W.LT.SUNW(1)) GO TO 50
      DO 30 K=2,NSUN
          K2=K
          IF (SUNW(K).GE.W) GO TO 40
20     CONTINUE
      40 K1=K2-1
          COM=(W-SUNW(K1))/(SUNW(K2)-SUNW(K1))
          SUN=SUNFLUX(K1)+COM*(SUNFLUX(K2)-SUNFLUX(K1))
          RETURN
25     50 SUN=0.
          RETURN
      END

```

## SUBROUTINE PLANKF

PLANKF is a subroutine of SRTGFCA. PLANKF calculates unattenuated surface emission using Planck's blackbody function. The surface temperatures and emissivities are read in SRTGFCA. The storage required is 1068 .

```
1      SUBROUTINE PLANKF(W,SURFCOM,NEMIS,NSURF)
C *** CALCULATE UNATTENUATED SURFACE EMISSION USING PLANCK FUNCTION
C      MONOCHROMATICALLY ***
      DIMENSION SURFCOM(10,10)
5      COMMON/CB/EMISS(10),TSURF(10)
      DATA C7/1.1906E-12/,C8/1.439/
      W3=W*W*W
      DO 10 I=1,NEMIS
        DO 10 K=1,NSURF
10      SURFCOM(I,K)=C7 *W3/(EXP(C8*W/TSURF(K))-1.)
        SURFCOM(I,K)=SURFCOM(I,K) *EMISS(I)
      10 CONTINUE
      RETURN
      END
```



# SUBROUTINE SUNNY

SUNNY is a subroutine of SRTGFCA. SUNNY calculates attenuated solar radiation reflected by the earth's surface using the Chapman function. The sun zenith angle is an input to SRTGFCA. The storage required is 608 .

```
1      SUBROUTINE SUNNY(W,NEMIS,SUNCOM,THETA,SUN,CHAPZEN)
C *** CALCULATE UNATTENUATED SOLAR RADIATION REFLECTED BY THE EARTH SURFACE
C      MONOCHROMATICALLY ***
      DIMENSION SUNCOM(10)
5      COMMON/CB/EMISS(10),TSURF(10)
      COSS=COS(THETA/57.2957795)
      CHAPZEN= CHAP(THETA)
      DO 10 I=1,NEMIS
        SUNCOM(I)=SUN *COSS *(1.-EMISS(I))
10     CONTINUE
      RETURN
      END
```

# FUNCTION CHAP

CHAP is a function of SRTGFCA called by subroutine SUNNY. CHAP determines slant path transmission by use of the Chapman polynomial. The storage required is 53<sub>8</sub> .

```

1      FUNCTION CHAP(THETA)
C *** DETERMINE SLANT PATH TRANSMISSION
C     FOR THETA .GT. 60. DEGREES, THE NATURAL LOG OF THE CHAPMAN FUNCTION IS
C     GIVEN BY AN 8 TH DEGREE POLYNOMIAL IN THETA ***
5      DATA PI/3.1415926535/
      IF (THETA.GT.60.) GO TO 20
      CHAP=1.0/COS(PI *THETA/180.)
      RETURN
10     20 XX=THETA
      POLY=((((( (-8.39732633E-13*XX +2.12740023E-10)*XX-9.45994657E-9)
1      *XX-1.37255804E-6)*XX +3.30591581E-5)*XX +2.30546152E-2)*XX
2      -2.44211940)*XX +9.78869273E+1)*XX -1.43635200E+3
      CHAP=EXP(-POLY)
      RETURN
15     END

```

# SUBROUTINES XNTEG, XNTEG2, XNTEG3, XNTEG4

XNTEG, XNTEG2, XNTEG3, and XNTEG4 are subroutines of SRTGFCA. They each integrate monochromatic values using the trapezoidal rule, and differ by the dimensions of the variables involved in the integration. The storage required for XNTEG, XNTEG2, XNTEG3, and XNTEG4 is 21<sub>8</sub>, 123<sub>8</sub>, 31<sub>8</sub>, and 77<sub>8</sub>, respectively.

```

1      SUBROUTINE XNTEG(DW1,VALNEW,VALOLD,SUM,K)
C *** INTEGRATE MONOCHROMATIC VALUES USING TRAPEZOIDAL RULE ***
      DIMENSION VALNEW(10),VALOLD(10),SUM(10)
      DO 50 IK=1,K
          SUM(IK)=SUM(IK) +(DW1/2) *(VALNEW(IK) +VALOLD(IK))
5      CONTINUE
      RETURN
      END

1      SUBROUTINE XNTEG2(DW1,VALNEW,VALOLD,SUM,KBI,NEMIS,NSURF,NXM)
C *** INTEGRATE MONOCHROMATIC VALUES USING TRAPEZOIDAL RULE ***
      DIMENSION VALNEW(100,2,2),VALOLD(100,2,2),SUM(100,2,2)
      DO 50 K=1,KBI
          DO 50 L=1,NEMIS
              DO 50 M=1,NSURF
                  DO 50 J=1,NXM
                      JJ=J +(K-1) *10
                      SUM(JJ,L,M) =SUM(JJ,L,M) +(DW1/2)* (VALNEW(JJ,L,M) +VALOLD(JJ,
10      L,M))
50      CONTINUE
      RETURN
      END

1      SUBROUTINE XNTEG3(DW1,VALNEW,VALOLD,SUM,K,NXM)
C *** INTEGRATE MONOCHROMATIC VALUES USING TRAPEZOIDAL RULE ***
      DIMENSION VALNEW(17,10),VALOLD(17,10),SUM(17,10)
      DO 50 IK=1,K
          DO 50 J=1,NXM
              SUM(IK,J)=SUM(IK,J) +(DW1/2)* (VALNEW(IK,J) + VALOLD(IK,J))
5      CONTINUE
      RETURN
      END

1      SUBROUTINE XNTEG4(DW1,VALNEW,VALOLD,SUM,K,NEMIS,NXM)
C *** INTEGRATE MONOCHROMATIC VALUES USING TRAPEZOIDAL RULF ***
      DIMENSION VALNEW(10,2,10),VALOLD(10,2,10),SUM(10,2,10)
      DO 50 IK=1,K
          DO 50 L=1,NEMIS
              DO 50 J=1,NXM
                  SUM(IK,L,J)=SUM(IK,L,J) + (DW1/2)* (VALNEW(IK,L,J) + VALOLD(IK,L,
10      L,J))
50      CONTINUE
      RETURN
      END

```

## OPERATING INSTRUCTIONS

### Input

The input from cards is divided into two sections. One section is the atmospheric data used by TRANSMT and its associated routines. The other section is the instrument data used by SRTGFCA and its associated routines.

The physical set-up for the TEMP, PRES, and THICK data is arranged such that all atmospheric layers are read in first, followed by the instrument cell layers to be considered, followed by an equal number of calibration cell layers. An option for no instrument and calibration layers is explained later.

In order to avoid unnecessary calculations, one should be careful in choosing the values of DELTAW and CMINV. For our sample case using carbon monoxide as the primary gas, 2070-2220  $\text{cm}^{-1}$  as the band width, DELTAW of .01  $\text{cm}^{-1}$ , and CMINV of 5  $\text{cm}^{-1}$ , a total of 12628 points of integration were considered. If DELTAW were chosen smaller and/or CMINV were chosen larger this total would be significantly greater causing execution time to increase.

Caution should be exercised concerning the units of the line parameters read from the spectral line tape. These units must be as specified in the dictionary of FORTRAN variables, and the reference temperature of the spectral lines must be 296.0K or the appropriate change to REFTEMP in the DATA statement in TRANSMT must be performed. A sample case input is listed in Appendix A.

### Options

Presently, one may choose either Lorentzian or Keilkopf's approximation to the Voigt (ref. 7) profile in the calculation of spectral line shape in program TRANSMT. The Doppler line

profile will be added in order to more accurately describe atmospheric conditions of low pressure and high temperature. It should be mentioned here that the Voigt profile requires a significant increase in calculation time.

By setting the value of NLAYI to zero, only atmospheric transmittance and radiance calculations are performed.

The program is currently set up to perform carbon monoxide calculations in the 4.6  $\mu\text{m}$  spectral band. Any other primary pollutant gas may be considered by setting the value of IPOLLUT to the identification number of that specie and by making necessary adjustments to band widths and filters. The gas broadening coefficient, BROAD, must also be changed to correspond to the gas being considered.

Program SRTGFCA simulates a gas filter correlation radiometer. Any infrared instrument using atmospheric transmittance and radiance information as input may be substituted for SRTGFCA.

It should be mentioned here that a routine to plot transmittance versus wavenumber as a function of altitude may be incorporated following the writing of the transmittance values on temporary storage disk 6 in TRANSMT.

The trapezoidal rule is used as the integration approximation in routines XNTEG, XNTEG2, XNTEG3, and XNTEG4. Should the user wish to incorporate a different integration process, these routines may be easily replaced. Similarly, that subroutine that determines the wavenumber mesh for integration may be replaced by an algorithm more suitable to the user.

### Output

The program output is in two sections. The first section lists the spectral lines used in the calculations, and the input data such as atmospheric profile and filter parameters. The second section is divided into two parts. Atmospheric output parameters, i.e., band integrated transmission and

total upwelling radiance as well as the band integrated components of the total radiance (solar, surface, and atmospheric), as a function of surface temperatures and emissivities are listed for the top of each atmospheric layer. The second part lists the corresponding instrument output responses in addition to calibration and balance output parameters as required by input instructions. If one sets NLAYI to zero, the instrument calibration will not be performed.

A sample case output is listed in Appendix B.

#### SAMPLE PROBLEM

The input listed in Appendix A and output in Appendix B correspond to a problem of determining the GFCR response of the instrument flying at the top of each of the first four modeled atmospheric layers. The model chosen is a  $45^{\circ}$  North Latitude July atmosphere with a corresponding water vapor profile (ref. 10). The sun zenith angle is  $45^{\circ}$ . The pollutant is carbon monoxide calculated at 10 different concentrations in each layer, with interferent constituent concentrations of water vapor and carbon dioxide held constant in each layer. The spectral band is  $4.6 \mu\text{m}$ , and the filter parameters simulate those of a NASA/LARC version of a GFCR.

#### COMPARISONS AND CONCLUSIONS

Obviously, any computer program is only as accurate as the theoretical model on which it is based and the accuracy of the numerical algorithms coded into program instructions. As outlined previously in the Problem Definition and Method of Solution section, the accuracy of this model is dictated by the assumptions made in our application to a specific problem.

In order to verify the results of the SMART calculated absorption coefficients, several comparisons were made with

existing experimental and theoretical absorption results in the CO fundamental band. The SMART program's algorithms for computing transmittance were checked against hand calculations for several wavenumbers and were shown to be correct. The high resolution absorption measurements,  $.05 \text{ cm}^{-1}$ , reported by Chaney and Drayson (refs. 11 and 12) for the R20 line of the  $4.6 \text{ }\mu\text{m}$  CO band was simulated by the SMART program, degraded, and compared. The absorption was computed at  $.01 \text{ cm}^{-1}$  intervals using the AFCRL line parameter data (ref. 5), then convoluted with a triangular slit transmission function whose width was  $.12 \text{ cm}^{-1}$  at half-maximum. The discrepancy found between the higher values of line strengths by Drayson (ref. 12) which were calculated from the measurements of Chaney (ref. 11), and the lower line strengths from the AFCRL line parameter tape, i.e., 1.11 and  $0.80 (\text{atm}^{-1}\text{cm}^{-1})_{\text{STP}}$ , respectively, for the R20 line, will be investigated further in the future. A preliminary comparison has shown no discrepancy between Drayson's line strengths near the CO fundamental band center, e.g., the R0 and P1 line. As the distance of a line from the band center increases, the discrepancy increases between the higher values of Drayson's line strengths and the lower AFCRL data line strengths (refs. 13, 14, 15, and 16). The SMART calculated spectrum is in excellent agreement with the experimental spectrum near the line center, and has only slightly higher values of absorption in the line wings. This deviation in the wings is probably due to the difference between the actual line profile (ref. 17) and the Lorentz line profile employed in our calculations. The absorption in the line wings calculated by SMART is in agreement with Burch and Gryvnak (ref. 18), who have shown that the extreme wings of the spectral lines are sub-Lorentzian. Despite the line wing shape differences, a comparison between the equivalent line width calculation using the Ladenberg and Reiche function (ref. 19) as described by Kondrat'Yev (ref. 20), and the SMART integrated absorption reveals less than 0.5 percent discrepancy in the total absorption by the R20 line under Chaney's test conditions.

SMART calculations of the entire CO fundamental band were performed and compared to the integrated absorption reported by the experimental work of Burch and Gryvnak (ref. 21). The SMART integrated absorption differed from the value reported by Burch by only 6.0 percent. This difference is probably due to a combination of an uncertainty in the reported experimental conditions and Burch's reported  $\pm 5.0$  percent instrumentation measurement error (ref. 21).

A line-by-line radiative transfer program that simulates a gas filter correlation radiometer has been developed and described. The overlaid structure allows for the substitution of the instrument simulation program with one that describes any infrared sensor. Any of the specific task subroutines may easily be substituted by algorithms that are more suitable and convenient to the user.

The program is currently constructed to perform carbon monoxide calculations in the fundamental  $4.6 \mu\text{m}$  spectral band, but by making necessary adjustments, other gas species transmittance calculations may be made. Future additions to the program will include the Doppler profile option (Lorentz and Voigt are presently incorporated), a sub-Lorentzian wing absorption algorithm, the water vapor and nitrogen continuum absorption algorithms, and a routine to plot transmittance as a function of wavenumber.

The storage required for the program is dependent upon the number of layers (atmospheric, instrument cell, and calibration cell) desired for consideration. For our sample case, 17 layers required 130300 octal words of storage and 838 seconds of execution time. Although this may appear to be a large amount of time and storage, the present program is equivalent to 32 separate computer runs of an earlier version of a radiative transfer program used at LaRC. By simultaneously performing several functions, such as balancing and calibrating, program efficiency increased, and a cost savings factor of five was realized.



A sample problem was processed. The resulting computer listing of input and output is shown.

# APPENDIX A

## Input Parameters for a Sample Test Case Listed as Card Images

| 17                            | 4         | 31     | 10      | 3  | 1 2  | 12    |
|-------------------------------|-----------|--------|---------|----|------|-------|
| 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 |           |        |         |    |      |       |
| 2070.                         | 2220.     | .01    | 5.      | 1  | 1.00 |       |
| 0.                            | .1        | .2     | .3      | .4 | .5   | .6 .7 |
| .8                            | 1.0       |        |         |    |      |       |
| 293.5                         | .9831     | 30480. |         |    |      |       |
| 292.1                         | .9497     | 30480. |         |    |      |       |
| 290.7                         | .9163     | 30480. |         |    |      |       |
| 289.3                         | .8837     | 30480. |         |    |      |       |
| 298.0                         | .8532     | 30480. |         |    |      |       |
| 286.6                         | .8228     | 30480. |         |    |      |       |
| 285.1                         | .7927     | 30480. |         |    |      |       |
| 283.4                         | .7649     | 30480. |         |    |      |       |
| 281.6                         | .7375     | 30480. |         |    |      |       |
| 311.5                         | .92105    | 1.     |         |    |      |       |
| 311.5                         | .92105    | 1.     |         |    |      |       |
| 311.5                         | .92105    | 1.     |         |    |      |       |
| 311.5                         | .92105    | 1.     |         |    |      |       |
| 298.5                         | .92105    | 2.     |         |    |      |       |
| 298.5                         | .92105    | 2.     |         |    |      |       |
| 298.5                         | .92105    | 2.     |         |    |      |       |
| 298.5                         | .92105    | 2.     |         |    |      |       |
| 1.0E-06                       | 1.844E-02 |        |         |    |      |       |
|                               |           |        | 3.2E-04 |    |      |       |
| 1.0E-06                       | 1.676E-02 |        | 3.2E-04 |    |      |       |
| 1.0E-06                       | 1.498E-02 |        | 3.2E-04 |    |      |       |
| 1.0E-06                       | 1.331E-02 |        | 3.2E-04 |    |      |       |
| 1.0E-06                       | 1.213E-02 |        | 3.2E-04 |    |      |       |
| 1.0E-06                       | 1.092E-02 |        | 3.2E-04 |    |      |       |
| 1.0E-06                       | 9.675E-03 |        | 3.2E-04 |    |      |       |
| 1.0E-06                       | 8.608E-03 |        | 3.2E-04 |    |      |       |
| 1.0E-06                       | 7.528E-03 |        | 3.2E-04 |    |      |       |
| .35                           |           |        |         |    |      |       |
| .35                           |           |        |         |    |      |       |

.35

.35

.08143

.08143

.08143

.08143

2 2 31 45.  
300. 296.  
.98 .88

|        |        |        |    |
|--------|--------|--------|----|
| 2070.0 | 0.0    | 0.0    | 1. |
| 2075.0 | .0050  | .0050  | 1. |
| 2080.0 | .0250  | .0250  | 1. |
| 2085.0 | .1060  | .1060  | 1. |
| 2090.0 | .1000  | .1000  | 1. |
| 2095.0 | .1550  | .1550  | 1. |
| 2100.0 | .2300  | .2300  | 1. |
| 2105.0 | .3500  | .3500  | 1. |
| 2110.0 | .4850  | .4850  | 1. |
| 2115.0 | .6250  | .6250  | 1. |
| 2120.0 | .7750  | .7750  | 1. |
| 2125.0 | .8700  | .8700  | 1. |
| 2130.0 | .9300  | .9300  | 1. |
| 2135.0 | .9700  | .9700  | 1. |
| 2140.0 | .9950  | .9950  | 1. |
| 2145.0 | 1.0000 | 1.0000 | 1. |
| 2150.0 | .0950  | .0950  | 1. |
| 2155.0 | .0650  | .0650  | 1. |
| 2160.0 | .0050  | .0050  | 1. |
| 2165.0 | .8100  | .8100  | 1. |
| 2170.0 | .6800  | .6800  | 1. |
| 2175.0 | .5350  | .5350  | 1. |
| 2180.0 | .4100  | .4100  | 1. |
| 2185.0 | .2850  | .2850  | 1. |
| 2190.0 | .1900  | .1900  | 1. |
| 2195.0 | .1400  | .1400  | 1. |
| 2200.0 | .0950  | .0950  | 1. |
| 2205.0 | .0650  | .0650  | 1. |
| 2210.0 | .0350  | .0350  | 1. |

|        |       |       |    |
|--------|-------|-------|----|
| 2215.0 | .0150 | .0150 | 1. |
| 2220.0 | .0050 | .0050 | 1. |

|       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 311.8 | 311.8 | 311.8 | 311.8 |       |       |       |       |
| 308.8 | 284.7 | 308.8 | 284.7 | 308.8 | 284.7 | 308.8 | 284.7 |
| 1.    |       |       |       |       |       |       |       |

## APPENDIX B

### Output Listing for a Sample Test Case

THE INVESTIGATED POLLUTANT IS CO  
 THE WAVENUMBER INTERVAL IS 2070.000 TO 2220.000  
 THE SUBINTERVAL OF INTEGRATION IS 10.000 CM-1  
 THE MINIMUM INTEGRATING INCREMENT IS .010 CM-1  
 THE NUMBER OF POINTS OF INTEGRATION IS 12628

#### FILTER FUNCTION

| WAVENUMBER | VACUUM RESP | GAS CELL RESP | DETECTOR RESP |
|------------|-------------|---------------|---------------|
| 2070.000   | 0.0000      | 0.0000        | 1.0000        |
| 2075.000   | .0050       | .0050         | 1.0000        |
| 2080.000   | .0250       | .0250         | 1.0000        |
| 2085.000   | .1060       | .1060         | 1.0000        |
| 2090.000   | .1000       | .1000         | 1.0000        |
| 2095.000   | .1550       | .1550         | 1.0000        |
| 2100.000   | .2300       | .2300         | 1.0000        |
| 2105.000   | .3500       | .3500         | 1.0000        |
| 2110.000   | .4850       | .4850         | 1.0000        |
| 2115.000   | .6250       | .6250         | 1.0000        |
| 2120.000   | .7750       | .7750         | 1.0000        |
| 2125.000   | .8700       | .8700         | 1.0000        |
| 2130.000   | .9300       | .9300         | 1.0000        |
| 2135.000   | .9700       | .9700         | 1.0000        |
| 2140.000   | .9950       | .9950         | 1.0000        |
| 2145.000   | 1.0000      | 1.0000        | 1.0000        |
| 2150.000   | .9950       | .9950         | 1.0000        |
| 2155.000   | .9650       | .9650         | 1.0000        |
| 2160.000   | .9050       | .9050         | 1.0000        |
| 2165.000   | .8100       | .8100         | 1.0000        |
| 2170.000   | .6800       | .6800         | 1.0000        |
| 2175.000   | .5350       | .5350         | 1.0000        |
| 2180.000   | .4100       | .4100         | 1.0000        |
| 2185.000   | .2850       | .2850         | 1.0000        |
| 2190.000   | .1900       | .1900         | 1.0000        |
| 2195.000   | .1400       | .1400         | 1.0000        |
| 2200.000   | .0950       | .0950         | 1.0000        |
| 2205.000   | .0650       | .0650         | 1.0000        |
| 2210.000   | .0350       | .0350         | 1.0000        |
| 2215.000   | .0150       | .0150         | 1.0000        |
| 2220.000   | .0050       | .0050         | 1.0000        |

# ATMOSPHERIC PARAMETERS

| LAYER | TEMP (K) | PRESS (ATM) | THICK (CM)  | PATH (ATH-CM) | CO        | H2O       | CO2       |
|-------|----------|-------------|-------------|---------------|-----------|-----------|-----------|
| 1     | 293.50   | .98310      | 3.04800E+04 | 2.99649E+04   | 1.000E-06 | 1.844E-02 | 3.200E-04 |
| 2     | 292.10   | .94970      | 3.04800E+04 | 2.89469E+04   | 1.000E-06 | 1.676E-02 | 3.200E-04 |
| 3     | 290.70   | .91630      | 3.04800E+04 | 2.79288E+04   | 1.000E-06 | 1.498E-02 | 3.200E-04 |
| 4     | 289.30   | .88370      | 3.04800E+04 | 2.69352E+04   | 1.000E-06 | 1.331E-02 | 3.200E-04 |
| 5     | 288.00   | .85320      | 3.04800E+04 | 2.60055E+04   | 1.000E-06 | 1.213E-02 | 3.200E-04 |
| 6     | 286.60   | .82280      | 3.04800E+04 | 2.50789E+04   | 1.000E-06 | 1.092E-02 | 3.200E-04 |
| 7     | 285.10   | .79270      | 3.04800E+04 | 2.41615E+04   | 1.000E-06 | 9.675E-03 | 3.200E-04 |
| 8     | 283.40   | .76490      | 3.04800E+04 | 2.33142E+04   | 1.000E-06 | 8.608E-03 | 3.200E-04 |
| 9     | 281.60   | .73750      | 3.04800E+04 | 2.24790E+04   | 1.000E-06 | 7.528E-03 | 3.200E-04 |
| 10    | 311.50   | .92105      | 1.00000E+00 | 9.21050E-01   | 3.500E-01 | 0.        | 0.        |
| 11    | 311.50   | .92105      | 1.00000E+00 | 9.21050E-01   | 3.500E-01 | 0.        | 0.        |
| 12    | 311.50   | .92105      | 1.00000E+00 | 9.21050E-01   | 3.500E-01 | 0.        | 0.        |
| 13    | 311.50   | .92105      | 1.00000E+00 | 9.21050E-01   | 3.500E-01 | 0.        | 0.        |
| 14    | 298.50   | .92105      | 2.00000E+00 | 1.84210E+00   | 8.143E-02 | 0.        | 0.        |
| 15    | 298.50   | .92105      | 2.00000E+00 | 1.84210E+00   | 8.143E-02 | 0.        | 0.        |
| 16    | 298.50   | .92105      | 2.00000E+00 | 1.84210E+00   | 8.143E-02 | 0.        | 0.        |
| 17    | 298.50   | .92105      | 2.00000E+00 | 1.84210E+00   | 8.143E-02 | 0.        | 0.        |

THE SUN ZENITH ANGLE IS 45.000 DEGREES

LAYER 1  
THE SPECTRAL LINE PROFILE IS LORENTZ

# ATMOSPHERIC OUTPUT PARAMETERS

THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

|                     |              |            |            |            |            |            |            |            |            |            |
|---------------------|--------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
|                     | 0.           | 1.0000E-07 | 2.0000E-07 | 3.0000E-07 | 4.0000E-07 | 5.0000E-07 | 6.0000E-07 | 7.0000E-07 | 8.0000E-07 | 1.0000E-06 |
| TRANS               | = 9.0869E-01 | 9.0450E-01 | 9.0053E-01 | 8.9676E-01 | 8.9318E-01 | 8.8976E-01 | 8.8650E-01 | 8.8337E-01 | 8.8038E-01 | 8.7476E-01 |
| TOTATM              | = 4.7195E-06 | 4.9182E-06 | 5.1066E-06 | 5.2856E-06 | 5.4559E-06 | 5.6183E-06 | 5.7733E-06 | 5.9217E-06 | 6.0638E-06 | 6.3314E-06 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| TOTSUN              | = 4.8823E-07 | 4.6696E-07 | 4.5384E-07 | 4.4404E-07 | 4.3596E-07 | 4.2897E-07 | 4.2273E-07 | 4.1705E-07 | 4.1180E-07 | 4.0231E-07 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| TOTSUN              | = 2.9294E-06 | 2.8017E-06 | 2.7230E-06 | 2.6642E-06 | 2.6158E-06 | 2.5738E-06 | 2.5364E-06 | 2.5023E-06 | 2.4708E-06 | 2.4139E-06 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 5.3556E-05 | 5.3311E-05 | 5.3079E-05 | 5.2859E-05 | 5.2649E-05 | 5.2449E-05 | 5.2259E-05 | 5.2076E-05 | 5.1901E-05 | 5.1572E-05 |
| TOTRAD              | = 5.8763E-05 | 5.8696E-05 | 5.8640E-05 | 5.8588E-05 | 5.8541E-05 | 5.8497E-05 | 5.8455E-05 | 5.8415E-05 | 5.8377E-05 | 5.8306E-05 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 4.6617E-05 | 4.6404E-05 | 4.6202E-05 | 4.6010E-05 | 4.5828E-05 | 4.5654E-05 | 4.5488E-05 | 4.5329E-05 | 4.5177E-05 | 4.4890E-05 |
| TOTRAD              | = 5.1824E-05 | 5.1789E-05 | 5.1763E-05 | 5.1740E-05 | 5.1720E-05 | 5.1701E-05 | 5.1684E-05 | 5.1668E-05 | 5.1653E-05 | 5.1624E-05 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 4.8091E-05 | 4.7871E-05 | 4.7663E-05 | 4.7465E-05 | 4.7277E-05 | 4.7097E-05 | 4.6926E-05 | 4.6762E-05 | 4.6605E-05 | 4.6309E-05 |
| TOTRAD              | = 5.5740E-05 | 5.5591E-05 | 5.5493E-05 | 5.5415E-05 | 5.5349E-05 | 5.5290E-05 | 5.5236E-05 | 5.5186E-05 | 5.5140E-05 | 5.5055E-05 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 4.1860E-05 | 4.1669E-05 | 4.1488E-05 | 4.1315E-05 | 4.1152E-05 | 4.0995E-05 | 4.0846E-05 | 4.0704E-05 | 4.0567E-05 | 4.0310E-05 |
| TOTRAD              | = 4.9509E-05 | 4.9389E-05 | 4.9317E-05 | 4.9265E-05 | 4.9223E-05 | 4.9188E-05 | 4.9156E-05 | 4.9128E-05 | 4.9102E-05 | 4.9055E-05 |

# INSTRUMENT OUTPUT PARAMETERS

RADVACB = 4.0824E-05  
RADGASB = 3.3833E-05  
TAUA = 8.2869E-01  
ERRDN = 2.6392E-09

THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

|                     |               |            |            |            |            |            |            |            |            |            |
|---------------------|---------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
|                     | 0.            | 1.0000E-07 | 2.0000E-07 | 3.0000E-07 | 4.0000E-07 | 5.0000E-07 | 6.0000E-07 | 7.0000E-07 | 8.0000E-07 | 1.0000E-06 |
| TRANS               | = 8.4226E-01  | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 |
| SURFACE EMISSIVITY  | = .980        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = 2.6875E-05  | 2.6840E-05 | 2.6810E-05 | 2.6784E-05 | 2.6759E-05 | 2.6736E-05 | 2.6714E-05 | 2.6693E-05 | 2.6674E-05 | 2.6637E-05 |
| RADGASA             | = 2.2270E-05  | 2.2263E-05 | 2.2256E-05 | 2.2249E-05 | 2.2243E-05 | 2.2236E-05 | 2.2230E-05 | 2.2223E-05 | 2.2217E-05 | 2.2205E-05 |
| RADGASE             | = 2.9195E-05  | 2.9187E-05 | 2.9180E-05 | 2.9174E-05 | 2.9167E-05 | 2.9161E-05 | 2.9154E-05 | 2.9148E-05 | 2.9142E-05 | 2.9129E-05 |
| DV                  | = -1.2146E-09 | 2.0897E-08 | 3.8468E-08 | 5.3762E-08 | 6.7548E-08 | 8.0173E-08 | 9.1835E-08 | 1.0267E-07 | 1.1278E-07 | 1.3111E-07 |
| V                   | = 2.2271E-05  | 2.2253E-05 | 2.2237E-05 | 2.2222E-05 | 2.2209E-05 | 2.2196E-05 | 2.2184E-05 | 2.2172E-05 | 2.2161E-05 | 2.2139E-05 |
| SURFACE EMISSIVITY  | = .980        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = 2.3686E-05  | 2.3668E-05 | 2.3654E-05 | 2.3642E-05 | 2.3632E-05 | 2.3622E-05 | 2.3613E-05 | 2.3605E-05 | 2.3597E-05 | 2.3582E-05 |
| RADGASA             | = 1.9630E-05  | 1.9626E-05 | 1.9622E-05 | 1.9618E-05 | 1.9615E-05 | 1.9611E-05 | 1.9608E-05 | 1.9605E-05 | 1.9602E-05 | 1.9595E-05 |
| RADGASE             | = 2.6554E-05  | 2.6550E-05 | 2.6546E-05 | 2.6543E-05 | 2.6539E-05 | 2.6536E-05 | 2.6532E-05 | 2.6529E-05 | 2.6526E-05 | 2.6520E-05 |

|                     |   |             |            |            |            |            |            |            |            |            |            |
|---------------------|---|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| DV                  | = | 1.0087E-09  | 1.2503E-08 | 2.0183E-08 | 2.6247E-08 | 3.1405E-08 | 3.5952E-08 | 4.0042E-08 | 4.3766E-08 | 4.7184E-08 | 5.3273E-08 |
| V                   | = | 1.9629E-05  | 1.9619E-05 | 1.9612E-05 | 1.9605E-05 | 1.9599E-05 | 1.9593E-05 | 1.9588E-05 | 1.9583E-05 | 1.9578E-05 | 1.9569E-05 |
| SURFACE EMISSIVITY  | = | .880        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = | 300.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = | 2.5501E-05  | 2.5422E-05 | 2.5371E-05 | 2.5331E-05 | 2.5296E-05 | 2.5266E-05 | 2.5238E-05 | 2.5212E-05 | 2.5188E-05 | 2.5144E-05 |
| RADGASA             | = | 2.1127E-05  | 2.1110E-05 | 2.1094E-05 | 2.1078E-05 | 2.1063E-05 | 2.1049E-05 | 2.1035E-05 | 2.1022E-05 | 2.1009E-05 | 2.0985E-05 |
| RADGASE             | = | 2.8052E-05  | 2.8034E-05 | 2.8018E-05 | 2.8003E-05 | 2.7988E-05 | 2.7973E-05 | 2.7960E-05 | 2.7946E-05 | 2.7934E-05 | 2.7909E-05 |
| DV                  | = | -4.8932E-09 | 4.2747E-08 | 6.8951E-08 | 8.6792E-08 | 1.0041E-07 | 1.1146E-07 | 1.2079E-07 | 1.2884E-07 | 1.3592E-07 | 1.4786E-07 |
| V                   | = | 2.1130E-05  | 2.1089E-05 | 2.1059E-05 | 2.1035E-05 | 2.1013E-05 | 2.0993E-05 | 2.0975E-05 | 2.0958E-05 | 2.0941E-05 | 2.0911E-05 |
| SURFACE EMISSIVITY  | = | .880        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = | 296.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = | 2.2637E-05  | 2.2574E-05 | 2.2536E-05 | 2.2510E-05 | 2.2488E-05 | 2.2469E-05 | 2.2453E-05 | 2.2439E-05 | 2.2425E-05 | 2.2401E-05 |
| RADGASA             | = | 1.8756E-05  | 1.8742E-05 | 1.8728E-05 | 1.8716E-05 | 1.8704E-05 | 1.8692E-05 | 1.8681E-05 | 1.8671E-05 | 1.8661E-05 | 1.8641E-05 |
| RADGASE             | = | 2.5681E-05  | 2.5666E-05 | 2.5653E-05 | 2.5640E-05 | 2.5628E-05 | 2.5617E-05 | 2.5606E-05 | 2.5595E-05 | 2.5585E-05 | 2.5566E-05 |
| DV                  | = | -2.8968E-09 | 3.5210E-08 | 5.2532E-08 | 6.2084E-08 | 6.7951E-08 | 7.1757E-08 | 7.4280E-08 | 7.5948E-08 | 7.7018E-08 | 7.7969E-08 |
| V                   | = | 1.8758E-05  | 1.8724E-05 | 1.8702E-05 | 1.8685E-05 | 1.8670E-05 | 1.8656E-05 | 1.8644E-05 | 1.8633E-05 | 1.8622E-05 | 1.8602E-05 |

# CALIBRATION OUTPUT PARAMETERS

|                           |   |             |
|---------------------------|---|-------------|
| TRANS                     | = | 8.9319E-01  |
| RADHOTC                   | = | 3.0296E-05  |
| RADCOLC                   | = | 1.3627E-05  |
| RADHOTV                   | = | 3.5813E-05  |
| RADCOLV                   | = | 1.7151E-05  |
| DVHOT                     | = | 6.1833E-07  |
| DVCOLD                    | = | -5.8639E-07 |
| VHOT                      | = | 2.9987E-05  |
| VCOLD                     | = | 1.3920E-05  |
| BALANCE OUTPUT PARAMETERS |   |             |
| RADHOT                    | = | 3.7086E-05  |
| RADCOLD                   | = | 1.5933E-05  |
| RADHOTG                   | = | 3.0736E-05  |
| RADCOLG                   | = | 1.3206E-05  |
| DVHOTB                    | = | 2.8268E-09  |
| DVCOLDB                   | = | 2.8268E-09  |
| VHOTB                     | = | 3.0734E-05  |
| VCOLDB                    | = | 1.3205E-05  |

LAYER 2  
THE SPECTRAL LINE PROFILE IS LORENTZ

# ATMOSPHERIC OUTPUT PARAMETERS

THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

|                     |              |            |            |            |            |            |            |            |            |            |
|---------------------|--------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
|                     | 0.           | 1.0000E-07 | 2.0000E-07 | 3.0000E-07 | 4.0000E-07 | 5.0000E-07 | 6.0000E-07 | 7.0000E-07 | 8.0000E-07 | 1.0000E-06 |
| TRANS               | = 8.6540E-01 | 8.5771E-01 | 8.5079E-01 | 8.4450E-01 | 8.3875E-01 | 8.3346E-01 | 8.2856E-01 | 8.2400E-01 | 8.1972E-01 | 8.1190E-01 |
| TOTATH              | = 6.7130E-06 | 7.0666E-06 | 7.3850E-06 | 7.6738E-06 | 7.9377E-06 | 8.1804E-06 | 8.4051E-06 | 8.6142E-06 | 8.8099E-06 | 9.1678E-06 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| TOTSUN              | = 4.7743E-07 | 4.5535E-07 | 4.4200E-07 | 4.3205E-07 | 4.2387E-07 | 4.1677E-07 | 4.1043E-07 | 4.0466E-07 | 3.9934E-07 | 3.8970E-07 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| TOTSUN              | = 2.8646E-08 | 2.7321E-06 | 2.6520E-06 | 2.5923E-06 | 2.5432E-06 | 2.5006E-06 | 2.4626E-06 | 2.4280E-06 | 2.3960E-06 | 2.3382E-06 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 5.0853E-05 | 5.0406E-05 | 5.0003E-05 | 4.9637E-05 | 4.9302E-05 | 4.8993E-05 | 4.8708E-05 | 4.8441E-05 | 4.8192E-05 | 4.7736E-05 |
| TOTRAD              | = 5.8043E-05 | 5.7928E-05 | 5.7830E-05 | 5.7742E-05 | 5.7663E-05 | 5.7590E-05 | 5.7523E-05 | 5.7460E-05 | 5.7401E-05 | 5.7293E-05 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 4.4262E-05 | 4.3873E-05 | 4.3522E-05 | 4.3203E-05 | 4.2912E-05 | 4.2643E-05 | 4.2395E-05 | 4.2163E-05 | 4.1946E-05 | 4.1549E-05 |
| TOTRAD              | = 5.1452E-05 | 5.1394E-05 | 5.1349E-05 | 5.1309E-05 | 5.1273E-05 | 5.1241E-05 | 5.1210E-05 | 5.1182E-05 | 5.1156E-05 | 5.1107E-05 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 4.5664E-05 | 4.5262E-05 | 4.4900E-05 | 4.4572E-05 | 4.4271E-05 | 4.3994E-05 | 4.3737E-05 | 4.3498E-05 | 4.3275E-05 | 4.2865E-05 |
| TOTRAD              | = 5.5241E-05 | 5.5061E-05 | 5.4937E-05 | 5.4838E-05 | 5.4752E-05 | 5.4675E-05 | 5.4605E-05 | 5.4541E-05 | 5.4480E-05 | 5.4371E-05 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 3.9745E-05 | 3.9396E-05 | 3.9081E-05 | 3.8795E-05 | 3.8533E-05 | 3.8292E-05 | 3.8069E-05 | 3.7861E-05 | 3.7666E-05 | 3.7309E-05 |
| TOTRAD              | = 4.9323E-05 | 4.9194E-05 | 4.9118E-05 | 4.9061E-05 | 4.9014E-05 | 4.8973E-05 | 4.8936E-05 | 4.8903E-05 | 4.8872E-05 | 4.8815E-05 |

## INSTRUMENT OUTPUT PARAMETERS

RADVACB = 4.0824E-05  
RADGASB = 3.3833E-05  
TAUA = 8.2869E-01  
ERRDN = 2.6392E-09

THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

|                     |               |            |            |            |            |            |            |            |            |            |
|---------------------|---------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
|                     | 0.            | 1.0000E-07 | 2.0000E-07 | 3.0000E-07 | 4.0000E-07 | 5.0000E-07 | 6.0000E-07 | 7.0000E-07 | 8.0000E-07 | 1.0000E-06 |
| TRANS               | = 9.4226E-01  | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 |
| SURFACE EMISSIVITY  | = .980        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = 2.6562E-05  | 2.6501E-05 | 2.6450E-05 | 2.6404E-05 | 2.6363E-05 | 2.6325E-05 | 2.6290E-05 | 2.6257E-05 | 2.6227E-05 | 2.6171E-05 |
| RADGASA             | = 2.2007E-05  | 2.1995E-05 | 2.1983E-05 | 2.1971E-05 | 2.1960E-05 | 2.1949E-05 | 2.1938E-05 | 2.1927E-05 | 2.1916E-05 | 2.1895E-05 |
| RADGASE             | = 2.8931E-05  | 2.8919E-05 | 2.8907E-05 | 2.8896E-05 | 2.8884E-05 | 2.8873E-05 | 2.8862E-05 | 2.8851E-05 | 2.8841E-05 | 2.8820E-05 |
| DV                  | = -4.8006E-09 | 3.3529E-08 | 6.4283E-08 | 9.0468E-08 | 1.1330E-07 | 1.3347E-07 | 1.5144E-07 | 1.6758E-07 | 1.8215E-07 | 2.0746E-07 |
| V                   | = 2.2009E-05  | 2.1978E-05 | 2.1951E-05 | 2.1926E-05 | 2.1903E-05 | 2.1882E-05 | 2.1862E-05 | 2.1843E-05 | 2.1825E-05 | 2.1792E-05 |
| SURFACE EMISSIVITY  | = .980        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = 2.3524E-05  | 2.3494E-05 | 2.3470E-05 | 2.3449E-05 | 2.3430E-05 | 2.3413E-05 | 2.3398E-05 | 2.3383E-05 | 2.3369E-05 | 2.3344E-05 |
| RADGASA             | = 1.9494E-05  | 1.9487E-05 | 1.9481E-05 | 1.9475E-05 | 1.9470E-05 | 1.9464E-05 | 1.9459E-05 | 1.9453E-05 | 1.9448E-05 | 1.9438E-05 |
| RADGASE             | = 2.6418E-05  | 2.6412E-05 | 2.6406E-05 | 2.6400E-05 | 2.6394E-05 | 2.6389E-05 | 2.6383E-05 | 2.6378E-05 | 2.6373E-05 | 2.6363E-05 |



|                     |   |             |            |            |            |            |            |            |            |            |            |
|---------------------|---|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| DV                  | = | -5.1766E-10 | 1.0340E-08 | 3.2138E-09 | 4.3463E-08 | 5.3190E-08 | 6.1731E-08 | 6.9334E-08 | 7.6165E-08 | 8.2348E-08 | 9.3129E-08 |
| V                   | = | 1.9494E-05  | 1.9478E-05 | 1.9465E-05 | 1.9454E-05 | 1.9443E-05 | 1.9433E-05 | 1.9424E-05 | 1.9415E-05 | 1.9407E-05 | 1.9392E-05 |
| SURFACE EMISSIVITY  | = | .880        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = | 300.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = | 2.5283E-05  | 2.5188E-05 | 2.5123E-05 | 2.5071E-05 | 2.5027E-05 | 2.4987E-05 | 2.4951E-05 | 2.4917E-05 | 2.4886E-05 | 2.4830E-05 |
| RADGASA             | = | 2.0945E-05  | 2.0924E-05 | 2.0904E-05 | 2.0885E-05 | 2.0867E-05 | 2.0850E-05 | 2.0833E-05 | 2.0817E-05 | 2.0801E-05 | 2.0771E-05 |
| RADGASE             | = | 2.7869E-05  | 2.7848E-05 | 2.7829E-05 | 2.7810E-05 | 2.7792E-05 | 2.7774E-05 | 2.7757E-05 | 2.7741E-05 | 2.7725E-05 | 2.7695E-05 |
| DV                  | = | -6.8533E-09 | 5.1010E-08 | 8.4677E-08 | 1.0872E-07 | 1.2760E-07 | 1.4319E-07 | 1.5642E-07 | 1.6787E-07 | 1.7791E-07 | 1.9474E-07 |
| V                   | = | 2.0948E-05  | 2.0898E-05 | 2.0862E-05 | 2.0831E-05 | 2.0803E-05 | 2.0778E-05 | 2.0755E-05 | 2.0733E-05 | 2.0712E-05 | 2.0674E-05 |
| SURFACE EMISSIVITY  | = | .880        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = | 296.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = | 2.2555E-05  | 2.2487E-05 | 2.2447E-05 | 2.2418E-05 | 2.2394E-05 | 2.2372E-05 | 2.2354E-05 | 2.2336E-05 | 2.2320E-05 | 2.2291E-05 |
| RADGASA             | = | 1.8688E-05  | 1.8672E-05 | 1.8658E-05 | 1.8644E-05 | 1.8631E-05 | 1.8619E-05 | 1.8607E-05 | 1.8596E-05 | 1.8585E-05 | 1.8564E-05 |
| RADGASE             | = | 2.5612E-05  | 2.5597E-05 | 2.5582E-05 | 2.5568E-05 | 2.5556E-05 | 2.5543E-05 | 2.5531E-05 | 2.5520E-05 | 2.5509E-05 | 2.5489E-05 |
| DV                  | = | -3.0074E-09 | 3.7371E-08 | 5.5812E-08 | 6.6507E-08 | 7.3629E-08 | 7.8775E-08 | 8.2694E-08 | 8.5784E-08 | 8.8285E-08 | 9.2072E-08 |
| V                   | = | 1.8689E-05  | 1.8654E-05 | 1.8630E-05 | 1.8611E-05 | 1.8594E-05 | 1.8579E-05 | 1.8566E-05 | 1.8553E-05 | 1.8541E-05 | 1.8518E-05 |

# CALIBRATION OUTPUT PARAMETERS

TRANS = 8.9319E-01  
 RADHOTC = 3.0296E-05  
 RADCOLC = 1.3627E-05  
 RADHOTV = 3.5813E-05  
 RADCOLV = 1.7151E-05  
 DVHOT = 6.1833E-07  
 DVCOLD = -5.8639E-07  
 VHOT = 2.9987E-05  
 VCOLD = 1.3920E-05

# BALANCE OUTPUT PARAMETERS

RADHOT = 3.7086E-05  
 RADCOLD = 1.5933E-05  
 RADHOTG = 3.0736E-05  
 RADCOLG = 1.3206E-05  
 DVHOTB = 2.8268E-09  
 DVCOLDB = 2.8268E-09  
 VHOTB = 3.0734E-05  
 VCOLDB = 1.3205E-05

LAYER 3  
THE SPECTRAL LINE PROFILE IS LORENTZ

# ATMOSPHERIC OUTPUT PARAMETERS

THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

|                     | 0.         | 1.0000E-07 | 2.0000E-07 | 3.0000E-07 | 4.0000E-07 | 5.0000E-07 | 6.0000E-07 | 7.0000E-07 | 8.0000E-07 | 1.0000E-06 |
|---------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| TRANS               | 8.3636E-01 | 8.2564E-01 | 8.1643E-01 | 8.0838E-01 | 8.0123E-01 | 7.9481E-01 | 7.8898E-01 | 7.8362E-01 | 7.7865E-01 | 7.6966E-01 |
| TOTATH              | 7.9081E-06 | 8.3869E-06 | 8.7973E-06 | 9.1550E-06 | 9.4715E-06 | 9.7553E-06 | 1.0013E-05 | 1.0249E-05 | 1.0468E-05 | 1.0863E-05 |
| SURFACE EMISSIVITY  | .980       |            |            |            |            |            |            |            |            |            |
| TOTSUM              | 4.6891E-07 | 4.4607E-07 | 4.3250E-07 | 4.2242E-07 | 4.1411E-07 | 4.0692E-07 | 4.0049E-07 | 3.9463E-07 | 3.8922E-07 | 3.7945E-07 |
| SURFACE EMISSIVITY  | .880       |            |            |            |            |            |            |            |            |            |
| TOTSUN              | 2.8135E-06 | 2.6764E-06 | 2.5950E-06 | 2.5345E-06 | 2.4847E-06 | 2.4415E-06 | 2.4029E-06 | 2.3678E-06 | 2.3353E-06 | 2.2767E-06 |
| SURFACE EMISSIVITY  | .980       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | 300.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | 4.9047E-05 | 4.8425E-05 | 4.7890E-05 | 4.7422E-05 | 4.7006E-05 | 4.6633E-05 | 4.6293E-05 | 4.5982E-05 | 4.5693E-05 | 4.5169E-05 |
| TOTRAD              | 5.7424E-05 | 5.7258E-05 | 5.7119E-05 | 5.6999E-05 | 5.6892E-05 | 5.6795E-05 | 5.6707E-05 | 5.6625E-05 | 5.6549E-05 | 5.6412E-05 |
| SURFACE EMISSIVITY  | .980       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | 296.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | 4.2688E-05 | 4.2147E-05 | 4.1681E-05 | 4.1274E-05 | 4.0912E-05 | 4.0588E-05 | 4.0292E-05 | 4.0021E-05 | 3.9769E-05 | 3.9314E-05 |
| TOTRAD              | 5.1065E-05 | 5.0980E-05 | 5.0911E-05 | 5.0851E-05 | 5.0798E-05 | 5.0750E-05 | 5.0706E-05 | 5.0664E-05 | 5.0626E-05 | 5.0556E-05 |
| SURFACE EMISSIVITY  | .880       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | 300.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | 4.4042E-05 | 4.3484E-05 | 4.3003E-05 | 4.2583E-05 | 4.2210E-05 | 4.1875E-05 | 4.1570E-05 | 4.1290E-05 | 4.1030E-05 | 4.0560E-05 |
| TOTRAD              | 5.4764E-05 | 5.4547E-05 | 5.4395E-05 | 5.4272E-05 | 5.4166E-05 | 5.4071E-05 | 5.3985E-05 | 5.3906E-05 | 5.3833E-05 | 5.3700E-05 |
| SURFACE EMISSIVITY  | .880       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | 296.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | 3.8332E-05 | 3.7846E-05 | 3.7428E-05 | 3.7062E-05 | 3.6738E-05 | 3.6446E-05 | 3.6181E-05 | 3.5937E-05 | 3.5711E-05 | 3.5302E-05 |
| TOTRAD              | 4.9054E-05 | 4.8909E-05 | 4.8820E-05 | 4.8752E-05 | 4.8694E-05 | 4.8643E-05 | 4.8597E-05 | 4.8554E-05 | 4.8514E-05 | 4.8442E-05 |

## INSTRUMENT OUTPUT PARAMETERS

RADVACB = 4.0824E-05  
RADGASB = 3.3833E-05  
TAUA = 8.2869E-01  
ERRDN = 2.6392E-09

THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

|                     | 0.          | 1.0000E-07 | 2.0000E-07 | 3.0000E-07 | 4.0000E-07 | 5.0000E-07 | 6.0000E-07 | 7.0000E-07 | 8.0000E-07 | 1.0000E-06 |
|---------------------|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| TRANS               | 8.4226E-01  | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 |
| SURFACE EMISSIVITY  | .980        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | 300.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | 2.6297E-05  | 2.6209E-05 | 2.6136E-05 | 2.6073E-05 | 2.6017E-05 | 2.5967E-05 | 2.5921E-05 | 2.5879E-05 | 2.5839E-05 | 2.5768E-05 |
| RADGASA             | 2.1784E-05  | 2.1767E-05 | 2.1750E-05 | 2.1733E-05 | 2.1717E-05 | 2.1701E-05 | 2.1685E-05 | 2.1670E-05 | 2.1654E-05 | 2.1625E-05 |
| RADGASE             | 2.8709E-05  | 2.8691E-05 | 2.8674E-05 | 2.8658E-05 | 2.8641E-05 | 2.8625E-05 | 2.8610E-05 | 2.8594E-05 | 2.8579E-05 | 2.8549E-05 |
| DV                  | -7.5854E-09 | 4.7781E-08 | 9.1044E-08 | 1.2663E-07 | 1.5662E-07 | 1.8231E-07 | 2.0460E-07 | 2.2415E-07 | 2.4145E-07 | 2.7076E-07 |
| V                   | 2.1788E-05  | 2.1743E-05 | 2.1704E-05 | 2.1670E-05 | 2.1638E-05 | 2.1610E-05 | 2.1583E-05 | 2.1558E-05 | 2.1534E-05 | 2.1489E-05 |
| SURFACE EMISSIVITY  | .980        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | 296.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | 2.3357E-05  | 2.3312E-05 | 2.3276E-05 | 2.3245E-05 | 2.3217E-05 | 2.3192E-05 | 2.3169E-05 | 2.3148E-05 | 2.3128E-05 | 2.3092E-05 |
| RADGASA             | 1.9354E-05  | 1.9345E-05 | 1.9336E-05 | 1.9327E-05 | 1.9319E-05 | 1.9311E-05 | 1.9302E-05 | 1.9295E-05 | 1.9287E-05 | 1.9272E-05 |
| RADGASE             | 2.6278E-05  | 2.6269E-05 | 2.6260E-05 | 2.6252E-05 | 2.6243E-05 | 2.6235E-05 | 2.6227E-05 | 2.6219E-05 | 2.6211E-05 | 2.6196E-05 |

|                     |   |             |            |            |            |            |            |            |            |            |            |
|---------------------|---|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| DV                  | = | -2.1434E-09 | 2.6095E-08 | 4.7206E-08 | 6.4440E-08 | 7.9026E-08 | 9.1621E-08 | 1.0265E-07 | 1.1241E-07 | 1.2113E-07 | 1.3607E-07 |
| V                   | = | 1.9355E-05  | 1.9331E-05 | 1.9312E-05 | 1.9295E-05 | 1.9279E-05 | 1.9265E-05 | 1.9251E-05 | 1.9238E-05 | 1.9226E-05 | 1.9204E-05 |
| SURFACE EMISSIVITY  | = | .880        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = | 300.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = | 2.5077E-05  | 2.4962E-05 | 2.4883E-05 | 2.4819E-05 | 2.4764E-05 | 2.4714E-05 | 2.4670E-05 | 2.4629E-05 | 2.4591E-05 | 2.4522E-05 |
| RADGASA             | = | 2.0772E-05  | 2.0747E-05 | 2.0723E-05 | 2.0701E-05 | 2.0679E-05 | 2.0658E-05 | 2.0638E-05 | 2.0618E-05 | 2.0599E-05 | 2.0563E-05 |
| RADGASE             | = | 2.7697E-05  | 2.7672E-05 | 2.7648E-05 | 2.7625E-05 | 2.7603E-05 | 2.7582E-05 | 2.7562E-05 | 2.7543E-05 | 2.7524E-05 | 2.7487E-05 |
| DV                  | = | -8.7233E-09 | 6.1094E-08 | 1.0302E-07 | 1.3348E-07 | 1.5750E-07 | 1.7725E-07 | 1.9392E-07 | 2.0824E-07 | 2.2071E-07 | 2.4141E-07 |
| V                   | = | 2.0777E-05  | 2.0717E-05 | 2.0672E-05 | 2.0634E-05 | 2.0600E-05 | 2.0569E-05 | 2.0541E-05 | 2.0514E-05 | 2.0489E-05 | 2.0442E-05 |
| SURFACE EMISSIVITY  | = | .880        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = | 296.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = | 2.2437E-05  | 2.2361E-05 | 2.2315E-05 | 2.2279E-05 | 2.2249E-05 | 2.2223E-05 | 2.2199E-05 | 2.2177E-05 | 2.2156E-05 | 2.2118E-05 |
| RADGASA             | = | 1.8590E-05  | 1.8572E-05 | 1.8556E-05 | 1.8540E-05 | 1.8526E-05 | 1.8512E-05 | 1.8498E-05 | 1.8486E-05 | 1.8473E-05 | 1.8450E-05 |
| RADGASE             | = | 2.5514E-05  | 2.5496E-05 | 2.5480E-05 | 2.5465E-05 | 2.5450E-05 | 2.5436E-05 | 2.5423E-05 | 2.5410E-05 | 2.5398E-05 | 2.5374E-05 |
| DV                  | = | -3.8366E-09 | 4.1621E-08 | 6.3659E-08 | 7.7635E-08 | 8.7821E-08 | 9.5818E-08 | 1.0238E-07 | 1.0791E-07 | 1.1267E-07 | 1.2048E-07 |
| V                   | = | 1.8592E-05  | 1.8551E-05 | 1.8524E-05 | 1.8501E-05 | 1.8482E-05 | 1.8464E-05 | 1.8447E-05 | 1.8432E-05 | 1.8417E-05 | 1.8390E-05 |

# CALIBRATION OUTPUT PARAMETERS

|                           |   |             |
|---------------------------|---|-------------|
| TRANS                     | = | 8.9319E-01  |
| RADHOTC                   | = | 3.0296E-05  |
| RADCOLC                   | = | 1.3627E-05  |
| RADHOTV                   | = | 3.5813E-05  |
| RADCOLV                   | = | 1.7151E-05  |
| DVHOT                     | = | 6.1833E-07  |
| DVCOLD                    | = | -5.8639E-07 |
| VHOT                      | = | 2.9987E-05  |
| VCOLD                     | = | 1.3920E-05  |
| BALANCE OUTPUT PARAMETERS |   |             |
| RADHOT                    | = | 3.7086E-05  |
| RADCOLD                   | = | 1.5933E-05  |
| RADHOTG                   | = | 3.0736E-05  |
| RADCOLDG                  | = | 1.3206E-05  |
| DVHOTB                    | = | 2.8268E-09  |
| DVCOLDB                   | = | 2.8268E-09  |
| VHOTB                     | = | 3.0734E-05  |
| VCOLDB                    | = | 1.3205E-05  |

LAYER 4  
THE SPECTRAL LINE PROFILE IS LORENTZ

# ATMOSPHERIC OUTPUT PARAMETERS

THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

|                     |              |            |            |            |            |            |            |            |            |            |
|---------------------|--------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
|                     | 0.           | 1.0000E-07 | 2.0000E-07 | 3.0000E-07 | 4.0000E-07 | 5.0000E-07 | 6.0000E-07 | 7.0000E-07 | 8.0000E-07 | 1.0000E-06 |
| TRANS               | = 8.1524E-01 | 8.0183E-01 | 7.9079E-01 | 7.8146E-01 | 7.7336E-01 | 7.6620E-01 | 7.5976E-01 | 7.5388E-01 | 7.4846E-01 | 7.3868E-01 |
| TOTATM              | = 8.6745E-06 | 9.2558E-06 | 9.7314E-06 | 1.0132E-05 | 1.0478E-05 | 1.0782E-05 | 1.1056E-05 | 1.1305E-05 | 1.1534E-05 | 1.1946E-05 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| TOTSUN              | = 4.6215E-07 | 4.3857E-07 | 4.2480E-07 | 4.1458E-07 | 4.0616E-07 | 3.9887E-07 | 3.9235E-07 | 3.8641E-07 | 3.8093E-07 | 3.7101E-07 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| TOTSUN              | = 2.7729E-06 | 2.6314E-06 | 2.5488E-06 | 2.4875E-06 | 2.4370E-06 | 2.3932E-06 | 2.3541E-06 | 2.3184E-06 | 2.2856E-06 | 2.2261E-06 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 4.7735E-05 | 4.6958E-05 | 4.6318E-05 | 4.5777E-05 | 4.5307E-05 | 4.4891E-05 | 4.4517E-05 | 4.4175E-05 | 4.3860E-05 | 4.3292E-05 |
| TOTRAD              | = 5.6872E-05 | 5.6653E-05 | 5.6475E-05 | 5.6323E-05 | 5.6190E-05 | 5.6072E-05 | 5.5965E-05 | 5.5866E-05 | 5.5775E-05 | 5.5610E-05 |
| SURFACE EMISSIVITY  | = .980       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 4.1545E-05 | 4.0869E-05 | 4.0312E-05 | 3.9841E-05 | 3.9432E-05 | 3.9070E-05 | 3.8745E-05 | 3.8448E-05 | 3.8174E-05 | 3.7679E-05 |
| TOTRAD              | = 5.0682E-05 | 5.0563E-05 | 5.0469E-05 | 5.0387E-05 | 5.0316E-05 | 5.0251E-05 | 5.0193E-05 | 5.0139E-05 | 5.0088E-05 | 4.9997E-05 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 4.2864E-05 | 4.2167E-05 | 4.1592E-05 | 4.1106E-05 | 4.0684E-05 | 4.0310E-05 | 3.9974E-05 | 3.9668E-05 | 3.9385E-05 | 3.8874E-05 |
| TOTRAD              | = 5.4311E-05 | 5.4054E-05 | 5.3872E-05 | 5.3725E-05 | 5.3598E-05 | 5.3486E-05 | 5.3384E-05 | 5.3291E-05 | 5.3204E-05 | 5.3047E-05 |
| SURFACE EMISSIVITY  | = .880       |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000    |            |            |            |            |            |            |            |            |            |
| TOTSURF             | = 3.7306E-05 | 3.6699E-05 | 3.6199E-05 | 3.5776E-05 | 3.5408E-05 | 3.5084E-05 | 3.4791E-05 | 3.4524E-05 | 3.4278E-05 | 3.3834E-05 |
| TOTRAD              | = 4.8753E-05 | 4.8586E-05 | 4.8479E-05 | 4.8395E-05 | 4.8323E-05 | 4.8259E-05 | 4.8201E-05 | 4.8147E-05 | 4.8098E-05 | 4.8007E-05 |

# INSTRUMENT OUTPUT PARAMETERS

RADVACB = 4.0824E-05  
RADGASB = 3.3833E-05  
TAUA = 8.2869E-01  
ERRDN = 2.6392E-09

THE CONCENTRATIONS OF THE INVESTIGATED POLLUTANT CONSIDERED ARE

|                     |               |            |            |            |            |            |            |            |            |            |
|---------------------|---------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
|                     | 0.            | 1.0000E-07 | 2.0000E-07 | 3.0000E-07 | 4.0000E-07 | 5.0000E-07 | 6.0000E-07 | 7.0000E-07 | 8.0000E-07 | 1.0000E-06 |
| TRANS               | = 8.4226E-01  | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 | 8.4226E-01 |
| SURFACE EMISSIVITY  | = .980        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 300.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = 2.6062E-05  | 2.5946E-05 | 2.5852E-05 | 2.5773E-05 | 2.5704E-05 | 2.5642E-05 | 2.5586E-05 | 2.5535E-05 | 2.5488E-05 | 2.5403E-05 |
| RADGASA             | = 2.1588E-05  | 2.1565E-05 | 2.1542E-05 | 2.1520E-05 | 2.1499E-05 | 2.1478E-05 | 2.1457E-05 | 2.1437E-05 | 2.1418E-05 | 2.1379E-05 |
| RADGASE             | = 2.8512E-05  | 2.8489E-05 | 2.8467E-05 | 2.8445E-05 | 2.8423E-05 | 2.8402E-05 | 2.8382E-05 | 2.8362E-05 | 2.8342E-05 | 2.8304E-05 |
| DV                  | = -9.9065E-09 | 6.3264E-08 | 1.1850E-07 | 1.6243E-07 | 1.9841E-07 | 2.2852E-07 | 2.5415E-07 | 2.7628E-07 | 2.9563E-07 | 3.2792E-07 |
| V                   | = 2.1593E-05  | 2.1533E-05 | 2.1483E-05 | 2.1439E-05 | 2.1400E-05 | 2.1364E-05 | 2.1330E-05 | 2.1299E-05 | 2.1270E-05 | 2.1215E-05 |
| SURFACE EMISSIVITY  | = .980        |            |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | = 296.000     |            |            |            |            |            |            |            |            |            |
| RADVACA             | = 2.3193E-05  | 2.3131E-05 | 2.3081E-05 | 2.3038E-05 | 2.3001E-05 | 2.2967E-05 | 2.2937E-05 | 2.2909E-05 | 2.2883E-05 | 2.2835E-05 |
| RADGASA             | = 1.9216E-05  | 1.9204E-05 | 1.9192E-05 | 1.9180E-05 | 1.9168E-05 | 1.9157E-05 | 1.9146E-05 | 1.9135E-05 | 1.9125E-05 | 1.9104E-05 |
| RADGASE             | = 2.6141E-05  | 2.6128E-05 | 2.6116E-05 | 2.6104E-05 | 2.6093E-05 | 2.6081E-05 | 2.6070E-05 | 2.6060E-05 | 2.6049E-05 | 2.6029E-05 |

|                     |               |             |            |            |            |            |            |            |            |            |
|---------------------|---------------|-------------|------------|------------|------------|------------|------------|------------|------------|------------|
| DV                  | • -3.7740E-09 | 3.5524E-08  | 6.4734E-08 | 8.8169E-08 | 1.0764E-07 | 1.2416E-07 | 1.3843E-07 | 1.5090E-07 | 1.6192E-07 | 1.8059E-07 |
| V                   | • 1.9218E-05  | 1.9186E-05  | 1.9159E-05 | 1.9136E-05 | 1.9114E-05 | 1.9095E-05 | 1.9077E-05 | 1.9060E-05 | 1.9044E-05 | 1.9014E-05 |
| SURFACE EMISSIVITY  | •             | .880        |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | •             | 300.000     |            |            |            |            |            |            |            |            |
| RADVACA             | •             | 2.4883E-05  | 2.4747E-05 | 2.4652E-05 | 2.4575E-05 | 2.4509E-05 | 2.4451E-05 | 2.4398E-05 | 2.4350E-05 | 2.4305E-05 |
| RADGASA             | •             | 2.0610E-05  | 2.0581E-05 | 2.0552E-05 | 2.0526E-05 | 2.0500E-05 | 2.0475E-05 | 2.0451E-05 | 2.0428E-05 | 2.0405E-05 |
| RADGASE             | •             | 2.7535E-05  | 2.7505E-05 | 2.7477E-05 | 2.7450E-05 | 2.7424E-05 | 2.7400E-05 | 2.7376E-05 | 2.7352E-05 | 2.7330E-05 |
| DV                  | •             | -1.0501E-08 | 7.2720E-08 | 1.2342E-07 | 1.6032E-07 | 1.8926E-07 | 2.1288E-07 | 2.3265E-07 | 2.4951E-07 | 2.6410E-07 |
| V                   | •             | 2.0615E-05  | 2.0544E-05 | 2.0491E-05 | 2.0445E-05 | 2.0405E-05 | 2.0369E-05 | 2.0335E-05 | 2.0303E-05 | 2.0273E-05 |
| SURFACE EMISSIVITY  | •             | .880        |            |            |            |            |            |            |            |            |
| SURFACE TEMPERATURE | •             | 296.000     |            |            |            |            |            |            |            |            |
| RADVACA             | •             | 2.2307E-05  | 2.2219E-05 | 2.2163E-05 | 2.2119E-05 | 2.2082E-05 | 2.2049E-05 | 2.2019E-05 | 2.1991E-05 | 2.1965E-05 |
| RADGASA             | •             | 1.8481E-05  | 1.8460E-05 | 1.8442E-05 | 1.8424E-05 | 1.8407E-05 | 1.8391E-05 | 1.8376E-05 | 1.8361E-05 | 1.8346E-05 |
| RADGASE             | •             | 2.5405E-05  | 2.5385E-05 | 2.5366E-05 | 2.5348E-05 | 2.5331E-05 | 2.5315E-05 | 2.5300E-05 | 2.5285E-05 | 2.5271E-05 |
| DV                  | •             | -4.9944E-09 | 4.7811E-08 | 7.5146E-08 | 9.3638E-08 | 1.0775E-07 | 1.1917E-07 | 1.2874E-07 | 1.3692E-07 | 1.4404E-07 |
| V                   | •             | 1.8483E-05  | 1.8437E-05 | 1.8404E-05 | 1.8377E-05 | 1.8353E-05 | 1.8331E-05 | 1.8311E-05 | 1.8292E-05 | 1.8274E-05 |

# CALIBRATION OUTPUT PARAMETERS

|                           |   |             |
|---------------------------|---|-------------|
| TRANS                     | • | 8.9319E-01  |
| RADHOTC                   | • | 3.0296E-05  |
| RADCOLC                   | • | 1.3627E-05  |
| RADHOTV                   | • | 3.5813E-05  |
| RADCOLV                   | • | 1.7151E-05  |
| DVHOT                     | • | 6.1833E-07  |
| DVCOLD                    | • | -5.8639E-07 |
| VHOT                      | • | 2.9987E-05  |
| VCOLD                     | • | 1.3920E-05  |
| BALANCE OUTPUT PARAMETERS |   |             |
| RADHOT                    | • | 3.7086E-05  |
| RADCOLD                   | • | 1.5933E-05  |
| RADHOTG                   | • | 3.0736E-05  |
| RADCOLG                   | • | 1.3206E-05  |
| DVHOTB                    | • | 2.8268E-09  |
| DVCOLDB                   | • | 2.8268E-09  |
| VHOTB                     | • | 3.0734E-05  |
| VCOLDB                    | • | 1.3205E-05  |

## APPENDIX C

### Unit Conversion

The authors wish to note that in the past various units have been used to define the line intensities; therefore, the following conversion factors may be helpful.

At standard temperature and pressure condition, STP,

$$1 \text{ (cm-atm)}_{\text{STP}} = 2.69 \times 10^{19} \text{ molecules/cm}^2 ;$$

however, at some temperature  $T'$  ,

$$1 \text{ (cm-atm)}_{T'} = \frac{273.15 \text{ K}}{T' \text{ K}} \times 2.69 \times 10^{19} \text{ molecules/cm}^2$$

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